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INFORMATION CIRCULAR

REVIEW OF LITERATURE ON CONDITIONING AIR FOR ADVANCEMENT OF HEALTH AND SAFETY IN MINES

PART II. NEED FOR AIR CONDITIONING INDICATED BY PHYSICAL QUALITY OF UNDERGROUND AIR

BY

D. HARRINGTON AND SARA J. DAVENPORT

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

REVIEW OF LITERATURE ON CONDITIONING AIR FOR ADVANCEMENT OF HEALTH AND SAFETY IN MINES 1/

PART II. NEED FOR AIR CONDITIONING INDICATED BY PHYSICAL QUALITY OF UNDERGROUND AIR

By D. Harrington 2/ and Sara J. Davenport 3/

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INTRODUCTION

This circular is part II of a series of papers reviewing the literature on air conditioning in mines with particular reference to the health, safety, and efficiency of employees. It deals with the physiological aspects of the principal physical qualities of mine air; part I (Information Circular 7001), chapters 1 to 3, discussed the physiological aspects of the chemical qualities of mine air, especially when contaminated with organic matter and noxious and toxic gases; part III will describe theoretical and practical methods of air-conditioning mines to try to correct or alleviate the conditions mentioned and will discuss the results attained by some of the systems now in use in various parts of the world.

With the present emphasis on the necessity for preserving the health of the Nation's defenders, industrial as well as military, attention should be called to the various conditions that may affect adversely their health and efficiency. One of the most important of these is exposure to abnormal air conditions, especially high temperatures and humidities. Therefore, it is believed that although the data presented here on the physiological effects of exposure to high temperatures are intended mainly for the mining and allied industries, they are applicable to many other defense industries as well as to conditions present in some activities of the Army and Navy.

The importance of the industrial phase of this subject, which no doubt will be augmented considerably by the greatly increased activity incident to the production of war materials, is emphasized in a report by the Metropolitan Life Insurance Co. (71) to the effect that excessive heat is charged with 3,537 deaths (1.6 percent) of all accident fatalities among insured industrial employees from 1911 to 1935; the standardized death rates due to excessive heat for the 25-years averaged 1.4 per hundred thousand.

An increasingly large number of American citizens must become adapted to the uncomfortable and at times very hot interior of tanks, submarines, and airplanes; and many others will be exposed to the heat and humidity of the tropics as well as to summer heat in the United States. These men will have to do hard physical work as, however highly it may have become mechanized, modern warfare continues to require great expenditure of physical energy for long periods (72), and the continued health and efficiency of the men demand that this work be done under the best possible conditions.

The principal physical qualities of mine air that affect the health, saf and efficiency of the miner are temperature, humidity, motion, and barometric pressure. Additional hazards to health and safety may result from compressed air and fogginess, especially in tunnels.

Optimum Temperature

Acclimatization (man's ability to adapt himself to changes in air conditions) and psychology (an intangible matter of habit and suggestion) are important influences that cannot be ignored in air conditioning(73). Althoug

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the human organism can adapt itself to a wide range of atmospheric conditions without apparent discomfort or injury to health, acclimatization to extreme conditions probably involves strain on the heat-regulating system and interferes with the normal physiologic functions of the human body (73).

The fact that thousands of years in the heat of Africa do not seem to have acclimated the Negro to a temperature averaging 80° F. or the northern races to extreme cold (although the effects are mitigated by artificial control) seems to indicate that adaptation to an environment averaging between 60° and 80° F. in temperature is a primitive trait. According to Huntington (74), people have the best health and physical vigor when the mean temperature for day and night together averages 60° to 70° F.; this seems to be equally true of races of the far north and those close to the equator. The range of the optimum temperature among diverse races is small in contrast to the great range of the mean temperature of the regions where they live (74).

From an extensive study of season of birth in connection with survival and length of life Huntington (74) has the following to say regarding optimum temperature:

> Therefore it seems like a primitive trait acquired in the early stages of existence of our species, and modified only a little by the diverse environments in which the various races of mankind have since lived. How slight the modification is may be judged from the fact that factory workers of west European descent in the northeastern United States work most effectively when the temperature averaged 60° F., whereas the Cuban in the cigar factories of Florida works most rapidly at a mean temperature of 70° or less. Again, although the Javanese are a thoroughly equatorial people, they have the best health and greatest energy when they live at such an altitude that the temperature averages 70° or lower instead of 80°, as is the case where most of them live.

Abnormal Temperatures

Abnormally high and low temperatures have great influence on physical activity, accidents, sickness, and mortality; according to Huntington (74), the seasons affect time of birth, rate of death in infancy, and length of life, as well as intelligence; and temperature appears to be the main factor in causing seasonal fluctuations, rising temperature having a much more important effect. However, he states that cool regions as well as cool seasons, provided they are not too cold, have great advantage over warm regions with respect to the production of eminent persons. Although a cool climate may not produce more persons whose inherited capacities are of unusually high order, apparently it endows them with the physical capacities needed to make their mental capacities productive. Climate and weather also exert a profound influence upon diet, occupation, and recreation (74), which in turn affect human morbidity and mortality.

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According to Mills (75), climate distinctly influences loss of body heat and output of energy and therefore plays an important role in the existence of man and other warm-blooded animals.

Less is known about the physiological effects of low temperatures than of high temperatures. Cold imposes an extra load upon the heat-producing organs and functions to maintain body temperature, the burden falling largely upon digestion, metabolism, blood circulation, and the kidneys and indirectly upon the nervous system. In extremely cold atmospheres, compensation by increased metabolism becomes inadequate (73). According to Mills (75), the effects on health and disease of very cold climates are similar to those of very hot climates, exposure to benumbing cold depressing vitality to a degree somewhat comparable to the heat depression of subtropical regions. Grow (75a) observed that the mental state of persons suffering from exposure to cold is similar to that of persons suffering from anoxemia. By experiments with animals and humans he was able to show that such exposure produced lowering of body temperature, slowing of circulation and respiration, lowering of the O_2 content of the arterial blood (of animals), and anoxemia of the tissue of both animals and man. Excessively low temperatures seldom are found in mines and therefore will not be given detailed consideration in this paper.

A report by the United States Public Health Service (76) on mortality due to heat in the drought areas of the United States in 1934 shows definitel the ill effects of an abnormally hot climate. The report states that the pea mortality rate for the week ended July 28, 1934 (with a weekly average maximum of more than 100°) was about twice the expected rate for that time of year. The following statement is taken from that report:

> If simple averages are made of the weekly rates in the eight cities, with definite peaks (Chicago, Cincinnati, Columbus, Des Moines, Indianapolis, Kansas City, Mo., Omaha, and St. Louis), one finds a mean death rate of 25.5 per 1,000 population (annual basis) for the week ending July 28, as compared with an expected or normal rate for this season of the year of 12.4 per 1,000, an excess of 106 percent in the mortality for that week.
>
> The weekly numbers of deaths under 1 year of age are too small to use as a basis for reliable rates except in very large cities. However, if the infant mortality rates (deaths under 1 year per 1,000 live births) are averaged for the eight cities, the means are fairly reliable. Averages similar to those made for mortality at all ages indicate an infant mortality rate of 110 per 1,000 live births for the week ending July 28, as compared with an expected rate of 49 per 1,000, based on the corresponding weeks of the 4 preceding years - an excess of 124 percent for the hot week. This excess is slightly greater than the excess of 106 percent in the general mortality rate for all ages.

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In terms of actual numbers, the excess deaths under 1 year of age account for only a small fraction of the total excess deaths during the week ending July 28. In the 8 weeks preceding the hot week, the average weekly number of infant deaths in the seven cities (exclusive of Chicago[4/]) amounted to 42 as compared with 92 in the hot week, an excess of 50 infant deaths. A similar computation for all deaths gives 740 as the average weekly number, with 1,538 deaths in the hot week, an excess of 798 deaths at all ages. The excess of 50 infant deaths for this week in the seven cities therefore accounts for only 6.3 percent of the total excess. Obviously the adult ages were also heavily affected, but no data are now available on the age at death attributed to heat stroke, there were many among old persons with chronic heart or other organic ailments whose death was hastened by the exceptional weather conditions. It is known also that diarrheal diseases are usually high among young children in hot weather.

Any final analysis of the relation of weather to these peaks in the death rate should take account of other conditions as well as temperature. The relative humidities in the drought-heat cities have been abnormally low; indeed with high humidities a temperature of 108° would be unbearable. The purpose of this note is merely to point out these exceptional rises in the death rate that appear to be associated with exceptionally high temperatures; no attempt is made to analyze the relative effect of the various weather conditions.

The report (76) states that the relative humidity in the drought-heat cities was abnormally low and that a temperature of 108° would have been unbearable with high humidity. Most authorities seem to consider that the physiologic effect of humidity is negligible unless it is high. However, Zwalenburg (77) has suggested that dehydration is a factor in all cases of heat prostration and sunstroke and cites the enormous quantity of fluid taken from the body under conditions of low humidity and high temperature, as shown by experience on the desert. He describes a case of severe heat prostration (the patient was unconscious) from exposure to high temperature and relatively low humidity in which rapid recovery took place through liberal administration of liquids. Striking improvement took place immediately after the intravenous injection of 1,000 cc. of a 5-percent solution of dextrose.

Barometric Pressure

Information on the effects of changes in barometric pressure is limited. Mills (75) states, however, that there are definite hints that storm changes in pressure cause profound disturbances in physiologic functions of mind and body. He refers to the experimental results of Smith (78) as the only ones of significance published so far. Smith's (78) experiments revealed a

4/ Chicago is omitted because it is so much larger than the other cities that it would affect the total unduly. If Chicago is included, the infant deaths represent an even smaller percentage of the total excess. Averages of the rates previously discussed included Chicago, but since a simple average of the eight rates was made, Chicago had the same weight as any of the smaller cities.

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positive water balance in the body with pressure reduction and a negative balance with pressure increase, body tissues seeming to act as a sponge in this respect. The pressure differences he used were of the same order as those that occur with the natural storm changes where his studies were made (Chicago).

According to Mills (75), acuity and physical accuracy suffer sharply with rapidly falling pressure, and suicides come in waves at such times.

CHAPTER 4. PHYSIOLOGICAL EFFECTS OF EXPOSURE TO ABNORMALLY HIGH TEMPERATURE AND HUMIDITY

Excessively high temperature and humidity are found in mines scattered over the world, especially in very deep metal mines, such as those of the Comstock lode in Nevada and some of the mines of Montana[5/], Arizona[6/], California (90° F.), and Michigan (80° to 90° F.) in the United States; the Morro Velho mine in Brazil; the mines of the South African Rand; and the Kolar gold mines of Mysore, India. Coal mines also may have high air and rock temperatures, a mine at Somerset, Colo., having strata (both coal and rock) temperatures of 160° to 180° F. In certain English coal fields that are being worked at or near a depth of 4,000 feet, air temperatures of 105.6° dry bulb and 89.8° wet bulb are found at the face, with a strata temperature of 114° F. (79). In many other mines in which these conditions may not be excessive, temperature and humidity are high enough to constitute a hazard to the health and efficiency of the workers.

General Effects

According to Moss (80), the problems arising from temperature and humidity in deep mining are mainly physiological, although perhaps there is a tendency to forget this in the many physical problems involved.

The effects of exposure to high atmospheric temperature and humidity have been considered as acute and chronic. The acute condition has been referred to as sunstroke when it results from exposure to the direct rays of the sun and heat stroke or heat exhaustion when the heat is from some other source or only indirectly due to the sun. In heat stroke the temperature of the body rises, and there are signs of congestion and nervous irritation; in heat exhaustion there are pallor, fainting, and collapse. Heat stroke is the commoner form. Although sometimes caused by the direct rays of the sun, it is produced much more frequently by a combination of high temperature and excessive moisture in a confined space (81).

5/ Average air temperatures at one Butte mine are 86° F. dry bulb and 83° F. wet bulb. Some mines have rock and water temperatures as high as 113° F.

6/ Rock temperatures at the Magma mine are 109° F. at the 2,000-foot level and 140° F. at the 4,000-foot level. In Butte, Mont., and Jerome, Ariz., extensive underground mine fires cause rock strata to have temperatures exceeding 200° F.

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According to Fiske (82), the etiology and incipiency of heat exhaustion need not be at variance with those of sunstroke, except in intensity; the assumption is tenable that in sunstroke the factors are so fulminating and of such an overwhelming character that heat production and loss are promptly deranged, whereas the symptoms of heat exhaustion represent the sustaining and finally failing efforts on the part of the human body to overcome its adverse environment.

Subjective Symptoms

During professional attendance on workmen suffering from the effects of exposure to high temperatures, Coplin (83) found that the constant symptom of which the patients complained most was "cramp," usually referred to the region immediately below the ensiform appendix, not infrequently associated with similar pains in the calves of the legs, occasionally in the back, sometimes also in the hypogastrium, and less commonly in the thighs and upper extremities. Difficulty in breathing, a feeling as of a weight on the chest, and general fatigue were experienced. Occasionally there was pain in the splenic or hepatic region, and in nearly all cases sharp and throbbing headache, temporal or supraorbital, rarely occipital. In some cases nausea was present, but vomiting occurred rarely. In a few cases diarrhea was present, but in the majority constipation preceded the attack. As a rule the patients felt cool, not infrequently chilly, when brought out of the intense heat. In a number of cases in which the temperature reached about 105° F. the patients were nauseated and attempted to vomit. The desire to urinate was constant, although often no urine was voided. Great thirst was experienced. Removal from the extreme heat often was followed by gradual return to normal of the body temperature, and only weakness, entirely disproportionate to the other symptoms, remained.

Apparently, however, "heat cramp" is not always the principal symptom, as, according to Drcosti (84), it is of negligible importance in the humid mines of the Witwatersrand.

In an investigation of heat cramps and heat prostration in hot industries, Starkov and Jikesh (85) divided the patients into two groups - those suffering from cramps and those in whom cramps were entirely absent - and concluded that heat cramps and heat prostration are separate diseases.

According to Talbott and his coworkers (86), the number of clinical syndromes 7/ associated with exposure to high environmental temperature is considerably less than the number of terms applied to them. Accord in naming this group of diseases is lacking, and they are termed variously heat cramps, "morbus Britannicus," heat exhaustion, heat prostration, heat stroke, heat pyrexia, thermic fever, sunstroke, siriasis, and insolation; some are used interchangeably for similar conditions, others have a restricted meaning for most observers. These investigators divided the clinical and laboratory data obtained in their study into six parts - severe heat cramps, mild heat cramps,

7/ A syndrome is a complex or set of symptoms occurring together.

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myalgia (muscular pain) and abdominal cramps simulating mild heat cramps, heat prostration, and heat pyrexia (fever). However, in their final analysis they class heat cramps, heat prostration, and heat pyrexia as clinical entities Heat cramps are characterized by a depletion of body water and sodium chloride; heat prostration is thought to be due to collapse of the surface circulation; and heat pyrexia is the result of failure of the heat-regulating mechanism.

During a study of 184 heat cases observed specifically for heat cramps, Heilman and Montgomery (87) were impressed by the dissimilarity of symptoms and signs caused by heat and have classified them into three distinct groups as heat cramps, heat exhaustion, and heat retention. The symptoms referable to these groups are described (87) as follows:

> Heat cramps. - Few conditions may be more abrupt and more dramatic than muscle cramps due to heat. For example, a furnace gang is working before a huge blazing furnace having a temperature of 1,500° F. The heater throws open the door and turns the pack; he puts down his tongs and falls doubled, writhing in agony upon the floor; recurring muscular twitchings attended by pain begin; violent paroxysmal cramps of the muscles of the trunk and extremities twist his body; his face is flushed, his pupils are dilated, and his expression is that of excruciating agony and distress. He complains of dizziness, tinnitus, and gastrointestinal cramps. The physician is called; physical examination shows the patient in excruciating pain, the skin cold and clammy, the temperature 99° F., the pulse strong and rapid, and the respirations rapid and irregular. The patient often vomits in projectile fashion water which is still cool although drunk several hours before. Spasms of the respiratory muscles are often sufficiently severe to interfere with breathing. There is usually profuse sweating, although there may be diminished or no perspiration and scantiness or suppression of urine.
>
> All degrees of severity of painful cramps of the body musculature and the gastrointestinal tract due to external heat are seen on any day during the summer months in the first-aid dispensary of any large steel mill. The cramps may be delayed for several hours, often not appearing until after the patient has reached his home. Prodromal periods vary from hours to days. Many of the patients believe that they could tell several days before that they were going to have heat cramps. Premonitory symptoms reported were diarrhea and vomiting, occurring as early as a week previously.
>
> The chief complaint of a heat cramp victim is usually pain in various groups of skeletal muscles which prevents the subject from continuing his work. It is interesting to note the predilection of certain groups of muscles for cramps. The muscles of the shoulders, of the calf, and the flexor group of the forearm are most commonly affected. The muscles of the abdominal wall and of the fingers are affected to a lesser degree. The vomiting quite likely is due to spasms of the smooth muscles of the gastrointestinal tract.

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Heat exhaustion. - Heat-exhaustion patients, on the other hand, present symptoms of faintness and prostration without cramps. Manifestations vary from "light-headedness" or tinnitus to an oppression or even to stupor and unconsciousness. When examined, the heat-exhaustion patient is found to be in a condition of shock with weak, rapid, thready pulse, low blood pressure, normal or subnormal temperature, and irregular respiration. The patient is apathetic, his eyes are sunken and fixed with a purposeless stare, and the pupils are dilated. Relaxed sphincters and gastric regurgitation are infrequent.

Heat retention. - Clinically the heat-retention cases are characterized by a rise in body temperature accompanied by nervous restlessness, headache (occipital usually), vertigo, and great excitement. Patients complain of tinnitus, photophobia, diplopia, and exhibit extreme emotional instability. These are admitted to the hospital in states of great excitement, even acute mania, laughing, crying, babbling incoherently of minutiae of which they are usually unmindful; extreme drunkenness is often simulated. A careful history reveals that heat retention is prone to occur in individuals who failed to perspire normally or who had perspired copiously for a while, then ceased to perspire. With the cessation of perspiration, micturition becomes frequent. Occasionally the onset may be abrupt and the subject may topple over in a stupor and may die with startling suddenness. The pupils may be dilated but are usually constricted, the skin is dry and burning, and petechial spots are common. The face is moderately livid. The pulse is variable but usually it is irregular and rapid, with rates from 120 to 140. The blood pressure is usually elevated, fibrillary contractions of various muscle groups may occur or there may be complete muscular relaxation and flaccidity. The respirations at first are rapid and labored, later irregular and stertorous. The body temperature of heat-retention subjects rises from 3° to 10° F. Rectal temperatures are often 3° to 4° higher than oral or axillary temperatures.

Sayers and Harrington (88) observed dizziness, physical weakness or exhaustion to a marked degree, inability to think quickly or accurately, and nausea and headache during exposure to the still, hot, humid atmosphere of metal mines. Drcosti (84) considers the dizziness, weakness, and collapse that result from exposure to high temperature and humidity as symptoms of a protective nature to prevent further exertion of an overtaxed heart.

Mills (75) refers to the confusion in medical circles concerning the classification of different types of heat cases, particularly regarding the differentiation of heat exhaustion from heat stroke. Although both are due to difficulty in dissipation of body heat, they differ widely in physiologic response and type of symptoms. He discusses these two types as follows:

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The person developing heatstroke does so because he has more heat to dissipate than his body can get rid of, so he develops fever and the various stroke symptoms. His rate of internal heat production actually seems to rise as his symptoms develop. The exhaustion case, on the other hand, responds to difficulty in heat loss by sharp curtailment in his heat production - too sharp, in fact. Combustion processes in the body seem intimately linked to function of the adrenal cortex, and in this sharp curtailment of heat production other functions of the adrenal cortex are likewise suddenly suppressed. Accompanying a fall in body temperature there is usually a sharp fall in blood pressure from loss of vascular tone, and a marked increase in tone of the gastroenteric musculature, with sphincter spasm and painful hyperperistalsis. Vomiting and diarrhea may be present and troublesome. Loss of vascular tone, with weakness and collapse, accompanied by increased tonicity in the gut tract - these form the background for the picture of heat exhaustion with its low body temperature and low internal heat production.

We have, then, the individuals who are most sensitive to heat and likely to develop heatstroke because of an inability to suppress internal heat production rapidly enough, or whose dissipating mechanism breaks down under stress. And we have, on the other hand, those who meet external heat with a too severe suppression of heat production, resulting in the train of symptoms characteristic of acute adrenal insufficiency. Naturally the handling of the two types of cases differs radically. In the one, heat loss must be facilitated with all possible speed to relieve the stroke conditions, while in the other stimulative or restorative measures are often needed.

Persons who fail to get sufficient restful sleep, or are in a subnormal physical condition because of illness or alcoholic excesses, show themselves especially prone to heatstroke or exhaustion. Provision of cool sleeping quarters, therefore, becomes of paramount importance during the severe heat waves that so often come during our American summer months.

One further point to be considered is the handling of nonfatal cases of heatstroke or exhaustion. These unfortunate people very frequently exhibit a greatly increased sensitivity to heat for many years, so that living becomes a problem. Severe and prolonged headaches form the most troublesome feature of their discomfort. An environment of stimulating quality is needed to provide greatest opportunity for their recovery and chance to lead a useful life; but they cannot stand climatic extremes of heat or cold, and stimulating places without such extremes are few in number over the earth.

Objective Symptoms

In his lectures on animal heat in 1876, Bernard (89) said that accordi to his experiments exposure to the "toxic effects of heat" produced a serie

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of constant and characteristic symptoms. The animal was at first slightly agitated, soon respiration and circulation were accelerated, the animal opened its mouth and panted, and in a short time the respiratory movements could not be counted; finally the animal fell in convulsions and died, more often suddenly, uttering cries. If the temperature was high enough, death followed so suddenly that the animal seemed as if struck by lightning.

The objective symptoms observed by Sayers and Harrington (88) were a rise in body temperature (in one case reaching 102° F. after less than 2 hours in hot, humid air); an increase in pulse rate that seemed more sensitive to exercise than normally; very profuse perspiration; and loss of weight, especially marked in men who had been employed under conditions of high temperature and humidity over a period of years, but occurring sometimes after exposure for only a few days.

In 1880 Raymond (90) gave the actual effect of heat on the miners in the mines of the Comstock lode as, first, excessive perspiration and, if this is not removed rapidly enough, faintness; increased pulse was noted, in one instance from 64 to 150 in a carman bringing a car out 1,200 feet and in another instance from 60 to 120 in a man walking through the drift. In the worst places men "wilted" under the work and were said to have "no pluck." An intelligent miner said that the first month of work after a long rest was hard; then came 3 months of feeling brisk, followed by a "dragged-out" sensation. Some of the men said they were "broken down" in hot drifts; 6 years was the time given in one instance as required for "breaking down."

A physician at Virginia City (90) declared there was not a sound heart in any man on the lode who had worked in a hot drift for 2 years. After long work in these drifts the men had a waxen color and were known as "tallow faces."

Freise (91) observed that the skin of all workers in the Morro Velho mine exposed to the same deep-mine atmosphere for a few months showed wrinkling on the face, back, and outer surface of the arms; the skin of some had turned gray, and that of others had become yellowish.

Watkins (92) believed that the ill effects of disturbance of heat equilibrium do not become manifest solely in acute illness such as heat stroke or heat exhaustion, but also in chronic affections such as diminished resistance to fatigue and disease and lowered physical efficiency. Workers exposed to heat hazard eventually drop out because of decreased working powers, poor health, or some degenerative disease for which predisposition has been created by working conditions. The effects of long-continued exposure to this hazard are slow and insidious and are evidenced in degenerative changes, such as arthritic and muscular rheumatism, chronic skin disorders, and arteriosclerosis. In addition, long-continued exposure to excessive heat gradually but surely lowers the general physical tone, even if no disease conditions becomes evident.

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Specific Effects

The effects of abnormal air temperature and humidity on the human body depend upon many variable and complex factors, knowledge of which is still comparatively slight, although during recent years the hitherto obscure subject of heat disease has become prominent as a field of exceptional clinical interest and significance in industrial medicine (87).

Effect on Body Temperature

Ordinarily body temperature is maintained at 98.6° F., although according to Reimann (93) approximately 10 percent of the normal population has a body temperature lower than 98° F. To maintain normal temperature heat production must be balanced by heat loss. In healthy persons this is automatic through action of the heat-regulating mechanism. The organs involved in heat production include the musculature, the liver, and the endocrine glands; those concerned primarily with heat loss are the blood vessels of the skin and lung and the sweat glands (94). It is believed generally (95) that body temperature is controlled by a two-sided mechanism that regulates internal heat production (chemical regulation) and regulates heat loss by automatic variati in the rate of cutaneous circulation and the operation of sweat glands (physi regulation).

According to Hill (96), the human body regulates its temperature by varying the blood circulation near the surface of the skin, and thus the heat loss by radiation and convection, by varying the output of sweat and consequent loss of heat by evaporation, and to a minor degree by varying respiration and evaporation from the respiratory membrane. Body temperature also can be regulated to a minor degree by taking hot or cold food and drink and baths; by varying the clothing worn and thus the loss by radiation, convection, and evaporation; and by exposure to sun and wind; by confinement in still air; and by artificial sources of heat or cold, fires, steam coils, co surfaces, fans, and similar means. The body thus regulates its heat success under all but extreme conditions, but it cannot do so in an atmosphere havin a wet-bulb temperature at or above body temperature, as heat loss by evapora tion and convection is insufficient or lacking entirely.

According to Gagge and his coworkers (97), there is a transitional zone the "zone of thermal neutrality" - extending from an operative temperature (the net physical effect of the surrounding walls and ambient air temperatur of 86° to 89° in which heat losses by radiation plus convection and by evaporation are approximately equal, just balancing the heat produced by metabol With a higher operative temperature the body tissues as a whole still are no heating, owing to the delicately regulated sweat-secreting mechanism of the body; this is called the zone of "evaporative regulation." As operative temperature increases above 89°, heat loss by radiation plus convection decreases, and above 95° radiation plus convection becomes positive, indica a net gain of heat to the body from air and walls. This gain, plus the hea

8/ Metabolism is the process by which living cells or organisms incorporate the substances obtained from food into a part of their own bodies.

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produced by metabolism, however, is balanced by a parallel increase in evaporation. In a relatively warm environment the temperature of the body is maintained approximately constant by changes in sweat secretion to balance the heat received from the environment.

Usually, adjustments of the body to external air conditions are accomplished so easily that a normal person is unconscious of the complex physiologic processes at work. However, the workings of the heat-regulating mechanism are extremely complex and are not well-understood. When the external temperature rises, the blood vessels of the skin dilate by reflex vasomotor action and probably by direct action of heat on the vessels. More blood flows through the skin, raising its temperature and therefore the heat loss. The rise is least in the skin of the forehead and trunk and greatest in the extremities, particularly the feet. If this method of cooling does not prevent a rise of body temperature, the sweat glands are thrown into full action by the stimulus of the heated blood flowing through the heat-regulating center (98). Acclimatization to extreme conditions involves a strain upon the heat-regulating system and interferes with the normal physiologic functions of the human body.

Limitations of heat-regulating mechanism of the body

With the invention of the thermometer in about 1600 more exact data on the temperature of animals could be obtained, and it became possible to make experiments to determine the point at which the heat-regulating mechanism of the body ceases to function in contact with heat or cold greater than the usual body temperature.

According to Manson (98), the healthy human body, when untrammeled by unsuitable clothing, when not exhausted by fatigue or excesses, and when not clogged by surfeit of food, by alcoholic drinks, or by drugs, can support with impunity very high temperatures. When, however, the physiologic activities have become impaired by disease, by excesses of any kind, by fatigue, by living in overcrowded rooms, or by a combination of some of these, then high atmospheric temperatures are badly supported, the heart may fail, and syncope (faintness) may ensue.

Cullen (99), who was a lecturer in medicine and chemistry at the University of Glasgow about 1775, offered many arguments to show that life itself had power of generating heat independent of any common chemical or mechanical means; before his time the accepted opinions were that the heat of animals arose either from friction or fermentation.

The Philosophical Transactions for 1775 (99) described a series of experiments and observations made in a heated room by Fordyce, who with others observed the effects of air heated to a much higher degree than it was formerly thought any living creature could bear, and convinced them by their own experience of the wonderful power of the animal body to resist a heat vastly greater than its own temperature. According to this article, Fordyce had proved the mistake of Boerhaave and most other authors by supporting many times very high degrees of heat in the course of many important experiments.

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In these experiments different persons, sometimes several at a time, remained for a number of minutes in rooms heated to 211° without symptoms other than that the air felt unpleasantly hot; their most uneasy feeling was a sense of scorching on the face and legs, which were bare. When the heat of the air began to approach the highest degree that the apparatus could produce, their bodies in the room prevented it from rising any higher; and when it had been raised previously above that point, their bodies inevitably reduced it. The results of these experiments were described as follows:

> These experiments therefore prove, in the clearest manner, that the body has a power of destroying heat. To speak justly on this subject, it must be called a power of destroying a certain degree of heat communicated with a certain quickness. Therefore, in estimating the heat which we are capable of resisting, it is necessary to take into consideration not only what degree of heat would be communicated to our bodies, if they possessed no resisting power, by the heated body, before the equilibrium of heat was effected; but also what time the heat would take in passing from the heated body into our bodies. In consequence of this compound limitation of our resisting power, we bear very different degrees of heat in different mediums. The same persons who felt no inconvenience from air heated to 211° could not bear quicksilver at 120°, and could just bear rectified spirit of wine at 130°; that is, quicksilver heated to 120° furnished, in a given time, more heat for the living powers to destroy, than spirits heated to 130°, or air to 211°.
>
> As animals can destroy only a certain quantity of heat in a given time, so the time they can continue the full exertion of this destroying power seems to be also limited; which may be one reason why we can bear for a certain time, and much longer than can be necessary to fully heat the cuticle, a degree of heat which will at length prove intolerable. Probably both the power of destroying heat and the time for which it can be exerted may be increased, like most other faculties of the body, by frequent exercise.

In some "Further Experiments and Observations in a Heated Room," made in April of the same year by nearly the same personnel as in the above-mentioned experiments, air heated to 240°, 261°, or 262° was entered. They found that the air felt very hot, but still by no means to such a degree as to give pain; on the contrary, Blagden (99) had no doubt of being able to support a much greater heat; and all the gentlemen present, who went into the room, were of the same opinion. However, after 7 minutes Blagden began to feel oppression in his lungs attended with a feeling of anxiety, which, gradually increasing for the space of a minute, led him to think it most prudent to stop the experiment, and he immediately left the room. His pulse, which was counted as soon as he got into the cool air, was 144 per minute.

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Experiments by Dobson (99) showed that an air temperature of 224° could be borne 10 to 20 minutes by different persons without a great rise in body temperature. His conclusions were that the human body keeps nearly its own temperature in air heated to 224°, or may even pass without injury into air heated to a much higher degree.

In 1842 Bernard (89) began experimenting to determine the mechanism of death under the action of heat. The first result he observed from these and later experiments was that animals cannot live indefinitely in a temperature higher than that of their body. They all die, but not in the same length of time; in general, the larger the mass of the animal, the quicker the death. On the other hand, the class of animal has an influence; birds are more sensitive to the toxic influence of heat than are mammals.

Killick (100) observed that air at wet-bulb temperatures up to 145° was tolerated; this is about the temperature at which proteins begin to undergo a change, and the physicochemical state of cell protoplasm is affected. The highest temperature at which moist air could be tolerated by subjects at work and therefore breathing more deeply averaged 135° F. For hot, dry air the limit of tolerance was much higher, averaging 335° at rest and 212° during work. Physiological reactions were not pronounced as the limits of tolerance were approached; a burning sensation was felt in the mouth and throat, and the palate and fauces were red; sweating was noticeably greater when the wet-bulb temperature of the inspired air was above body temperature.

Body temperature and heat disease

The following interesting correlation of body temperature with clinical diagnosis of different types of heat disease has been reported by Talbot and coworkers (86): In cases diagnosed as moderate heat cramps, rectal temperatures ranged between 99.9° and 100.4°. In severe heat cramps the rectal temperature was 104.6° in one case but did not exceed 100.2° in the others. Rectal temperatures in patients diagnosed as suffering from myalgia and abdominal cramps ranged between 98.6 and 100.8° F. In cases diagnosed as heat prostration the rectal temperature ranged between 99.0° and 102.0° F. but had returned to normal by the next morning. In three cases diagnosed as heat pyrexia the rectal temperature on admission ranged between 101.4° and 102.6° F. with a duration of the fever for 1, 3, and 21 days, respectively.

In cases diagnosed by Heilman and Montgomery (87) as mild or moderate heat cramps and slight to severe heat exhaustion, temperatures ranged between 96.2° and 100°; in those diagnosed as moderate to severe heat retention, temperatures ranged between 104.2° and 108°. The rise in body temperature of heat-retention subjects was 3° to 10° F., and rectal temperatures often were 3° to 4° higher than oral or axillary temperatures.

From an investigation of the problems incident to exposure of South African native miners to high temperature and humidity, Dreosti (101) concluded that the condition of heat collapse is not the result of a disorganized heat-regulating mechanism or an unduly high rise in body temperature. None of the five native subjects who were withdrawn from the experimental chamber

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owing to signs of collapse had a temperature above 100° F., although the temperature of some who did not collapse rose to 104° and over. Dreosti (101) considers that the apparent absence of discomfort among the natives with high final temperatures is of special importance in relation to heat stroke, as this condition is more likely to occur in natives whose body temperature already has reached a high level but who, feeling no discomfort, continue to work until, with still further rise in body temperature, their heat-regulating mechanism fails entirely.

As a result of his numerous investigations on the acclimatization of native miners Dreosti (101) states that rise in body temperature has been the most consistent, reliable, and accurate index of the degree of acclimatizatio in other words, individual acclimatization and susceptibility to heatstroke can be measured. Investigations conducted by the Bureau of Mines (108) indicate that pulse rate probably is the best index of discomfort resulting from exposure to high air temperatures. (Note statement on page 40 under "pulse rate.")

Effect on Circulatory System

Circulation is the movement of the blood in the vessels of the body caus by the pulsations of the heart. The heart and the blood vessels form a vascu lar system containing a certain amount of blood, which is kept in circulatio mainly by the force of the muscular contractions of the heart. According to Howell (102), in general terms the functions of the blood are to carry to the tissues foodstuffs that have been prepared by the digestive organs; to trans port to the tissues oxygen absorbed from the air of the lungs; to carry off from the tissues various waste products; to act as a means of transmission o the internal secretion of certain glands; and to aid in equalizing the temperature and the water content of the body.

The pulse is the regular beating or throbbing caused in the arteries by contraction of the ventricles of the heart.

Air conditions that have the greatest effect on the circulatory system are humidity, temperature, air movement, and barometric pressure (103). A marked increase in relative humidity tends to depress the circulatory syster and decrease the blood pressure; a marked decrease in temperature stimulates the circulatory system and decreases the blood pressure. A marked increase in barometric pressure increases the blood pressure (103), while a marked f in barometric pressure increases the pulse rate.

As clinical examination of cases of heat collapse points to the essent causal relationship of circulatory insufficiency, Weiner (104) carried out experiments to determine the reactions of the circulatory system that const tute normal or physiological adaptation to hot surroundings and what failur in these processes brings about the pathological condition associated with heat collapse. The subjects of the experiment were adult male Bantus who had been passed by the examining medical officer of the City Deep gold mine Johannesburg, S. A., as fit for employment in the mine.

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The experiments, which were designed to represent conditions in actual practice in which heat collapse occurs, are described by Weiner (104) as follows:

> The subjects carried out a set task which consisted in shoveling gravel for 1 hour in a room at a wet-bulb temperature of 94°-95° F. and a dry-bulb temperature of 96°-98° F. The work was interrupted four times for the taking of observations. After this period of work the subject remained in the same atmospheric conditions for a further period. During this time he was required to stand upright without supporting himself in any way. He held himself at "attention", i.e., he kept his arms at his sides and his heels fairly close together but without rigidity or tenseness in his bearing. Of 36 subjects who underwent the experiment all but 6 appeared to be quite unaffected. These unaffected subjects remained standing for 1 hour and thereafter were withdrawn to a room at ordinary temperature where they were allowed to sit down while observations were continued for another hour. The 6 affected subjects evinced great distress after standing for varying periods in the hot room and could not remain in the upright position. When these individuals exhibited this fainting condition they were withdrawn to the cooler room and allowed to lie down while observations were continued during their recovery. Comparison of these two groups allows one to distinguish reactions characteristic of collapse. However, since standing even in the cool is known to cause collapse in some persons under certain conditions, it was thought necessary to arrange a third series of experiments in which the subjects worked in the hot room at ordinary temperature for a further period (which usually exceeded 1 hour), and thereafter sat down for an hour's observation. This series serves as a control for the other experiments. No collapses were observed amongst the 20 subjects employed and the cases of syncope observed previously are therefore conditioned by the factor of the hot environment besides personal susceptibility.
>
> The observations made in these experiments comprised the pulse rate, the systolic and diastolic blood pressures, the respiratory rate, and the oral temperature.

In addition to the objective measurements, the subjects were questioned as to their sensations and impressions throughout the experiments. Only 6 of 36 subjects collapsed during the experiments. The author draws the following conclusions from these experiments:

> Heat collapse can be induced in certain individuals by keeping them in the erect position in severe hot and humid conditions. The collapse and the associated circulatory findings are explained as being due to extensive vasodilatation of the peripheral vascular bed with consequent "pooling"

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of the blood by action of heat. This vasodilatation is indicated by an extreme fall in blood pressure, whilst as a result of an inadequate supply of blood to the brain, the anoxemia brings on slowing of the heart. In subjects who do not collapse under these circumstances it appears that the degree of vasodilatation is such that a compensatory acceleration of the heart rate and output to maintain an adequate circulation rate is possible. This shows itself in a steady fast pulse rate and uniform, though lowered, blood pressure. The collapse is easily differentiated from heat stroke and heat cramps.

Pulse rate

From various observations recorded by him, Haldane (105) concluded that the increase in pulse rate usually was about 20 beats a minute for each 1° F. of increase in rectal temperature, or 36 beats for each 1° C. while the subject was standing in the warm air, the increase being about a fourth less in the sitting posture. On return to cool air there was, however, an immediate drop in the pulse rate, so that the increase in the pulse rate was only 10 per minute per 1° F. of increased rectal temperature in the standing positio and 8 beats in the sitting position. The increase in pulse rate thus depend not merely on the rectal temperature but also on the external (wet-bulb) tem perature.

Palmer (106) found that a change as little as that from 68° to 75° produced a visible reaction in the body mechanism in a very short time. In a 75° atmosphere the pulse in one series of experiments rose from 79 in the morning to 89 in the late afternoon, an increase of 10 beats a minute. At 68° the pulse rate of the same subjects fell from 83 to 70 in the course of the day, a drop of 13 beats. The warmer room thus placed upon the heart the additional strain of 23 beats a minute.

According to Johnson (107), the pulse rate corresponds roughly to the temperature; with a temperature of 110° F. or higher the pulse rate is 150 t 180, and with continued hyperpyrexia it becomes imperceptible.

In a cooperative study by the Bureau of Mines, the Public Health Servic and the American Society of Heating and Ventilating Engineers (108), the importance of the circulatory system was emphasized by experiments in which su jects were exposed to abnormal atmospheric conditions. These investigations led to the conclusion that the pulse rate would be selected as probably the best index of discomfort due to high temperature if a single physiologic mea were the basis of consideration. Investigators have long recognized that b temperature alone does not cause the discomfort, and their conclusions as a whole correspond to those of Haldane, who stated that the discomforts produc by high temperatures undoubtedly depend to some extent on other causes than rise of body temperature, as indicated by the rectal temperature. It frequ happened in these experiments that the rectal temperature rose slightly aft the subject left the chamber; nevertheless, he felt more comfortable with t fall in pulse rate. Although no arbitrary rate at which certain symptoms occur has been determined, the consensus of opinion indicates that very unc fortable sensations are felt after the pulse rate exceeds 135 per minute, a

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the atmospheric condition becomes unbearable and the subject desires to leave the chamber immediately when the rate exceeds 160 per minute. Several experiments revealed that some subjects attained a high pulse rate much sooner than others who were exposed to the same conditions and therefore were compelled to leave the chamber sooner. In one instance, a man attained a pulse rate of 160 in 10 minutes, while another remained in the chamber 35 minutes before the pulse reached 180. In the next experiment, one attained a pulse rate of 160 a minute in 35 minutes, while another remained 1 1/2 hours and the pulse reached only 156 a minute. In a third experiment, the pulse of one reached 142 in 25 minutes, while that of another reached 156 in 45 minutes. The pulse rate diminished rapidly after the subjects left the test chamber.

The following table gives the temperatures and pulse rates of 13 heat-disease patients examined by Heilman and Montgomery (87), grouped according to the three classes suggested by these investigators:

TABLE 1. - Temperature and pulse rates of heat-disease patients

Heat cramps		Heat exhaustion				Heat retention 2/			
Moderate		Moderate		Severe		Moderate		Severe	
Temp., °F.	Pulse rate	Temp., °F.	Pulse rate	Temp., °F.	Pulse rate	Temp., °F.	Pulse rate	Temp., °F.	Pulse rate
98.3	92	97.0	86	96.2	Weak 1/	105.2	102	108	145
99.0	86	98.3	76			104.2	98		
100.0	102								
98.3	80								
99.0	80								
99.2	88								
98.0	82								

1/ This patient was unconscious, with pulse so weak that it could not be counted; after return of consciousness the pulse was 125.
2/ Attention is called to the higher temperatures and pulse rates in cases diagnosed as "heat retention."

Dreosti (101) could find no correlation between pulse rate and rise in body temperature and stated that the pulse rate is not an indicator of the efficiency of the control of body temperature.

According to Adolph and Fulton (109), the peripheral blood vessels are greatly dilated during exposure to high temperature, and this dilation continues indefinitely. The lack of high resistance in the peripheral blood vessels prevents blood from returning to the heart. The heart rate increases steadily and rapidly and is even able to increase the systolic blood pressure. In spite of this compensating activity on the part of the heart, the blood flow back to the heart finally becomes inadequate. At this point circulatory failure or shock is complete, with faintness. The rise in skin temperature seems to play the initiatory part in the control of the respiratory and circulatory reactions.

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As a result of studies on the effect of various temperatures and humidities on the heart rate, pulse rate, and blood pressure, the New York Ventilation Commission (110) found that exposure of subjects to an atmosphere of 20° (68°F.) and a relative humidity of 50 percent for 4 to 8 hours was accompanied by a decrease in the heart rate, averaging 11 beats a minute when the body was reclining and 18 beats when it was standing. At 24° C. (75° F.), 50 percent relative humidity, there was only a negligible change in the heart rate; at 30° C. (86° F.), 80 percent relative humidity, there was an increase in the rate of the heart in the standing position and in the reclining position a negligible average decrease. Exposure to 38° C. (100.5° F.), with relative humidity 86 percent, for 2.43 hours, was accompanied by an average increase in the rate of the heart of 28 beats a minute (43 percent), the average maximum increase being 41 beats (63 percent). When the experimental subjects increased the rate of the heart beat by performing physical work in the two atmospheres of 20° C. (68° F.) and 24° C. (75° F.), the humidity being the same, the heart returned to the original rate slightly earlier in the cooler air. The systolic and diastolic blood pressures of the experimental subjects in the three moderate atmospheric conditions studied exhibited no marked changes; but subjection of an individual to the more extreme condition of 38.3° C. (101° F.), 87 percent humidity, for 2.5 hours was accompanied by an average increase of systolic pressure of 12.6 mm. (12 percent) and of diastolic pressure of 1.4 mm. (2 percent), the respective average maxima being 22 and 16 percent.

Kennedy (111) states that in hot weather it is not unusual for men to work on hot jobs for 8 hours with their hearts averaging, during work, 140 beats a minute. Men accustomed to the work show no ill effects when their hearts beat at twice the normal rate, provided they have normal rest during their hours away from work. However, if rest is not obtained at home, or if their heart reserve has been diminished by disease of the heart muscle, they are subject to heat exhaustion.

According to Dreosti (101), the heart has two distinct functions to perform in persons doing muscular work in a hot environment: It must increase its action to supply more blood to the blood vessels of the skin to facilitate heat dissipation and to convey more oxygen to the muscles by increased blood flow, which causes a marked increase in the rate and action of the heart. Pulse rate and blood pressure are indexes of the strain at which the heart is working and not of the ability to control rise in body temperature, and acclimatization is accompanied by "acclimatization of the heart." A fatigued heart gives rise to symptoms of dizziness, weakness, or even collapse. Such symptoms in a normal, healthy person are protective in nature. By forcing cessation of work they protect the already overtaxed heart from still further exertion. The strain that produces symptoms of a fatigued heart in a normal, healthy person may be sufficient to cause a complete break-down of the heart's action and therefore death in a person whose heart has been damaged by previous heart disease or by the poisons of any other disease.

According to Martin (112), it is not necessary to look beyond the mammalian heart itself to account for the quick pulse of fever; a theoretical

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assumption of paralysis of inhibitory or excitation of accelerator cardio-extrinsic nerve centers is not required. The experiments show that in spite of its highly developed extrinsic nervous apparatus, as far as its rhythm is concerned, in its own neuromuscular tissues the heart of the mammal responds to temperature variations within wide limits (42° to 27° C.- 80° to 108°F.) just as does the frog's heart or the heart of the embryo chick.

Sedgwick (113) mentioned the fact that while physiologists were not agreed as to the effects upon reflex actions of changes in temperature, it was generally known that with a gradual rise of temperature protoplasm passes from almost complete inactivity at a low temperature little by little into a phase of greatest activity, beyond which under excessive heat its functions fall rather quickly back to zero or, if the temperature is raised still higher, pass beyond and disappear with the occurrence of coagulation and death. He found from experiments that in obedience to the laws of protoplasm the heart always beats faster when fed heated blood. An increase in heart rate due to increased accelerator tone, caused by increased temperature of the carotid blood, was noted by Moorhouse (114) in experiments on dogs.

Blood

According to Bernard (89), the only modification of the blood caused by heat is a sort of exaggeration of its physiologic properties that leads to too rapid consumption of oxygen by the globules and that there is a limit of temperature at which the blood loses forever its physiologic property.

In 1908 Wickline (115) reported results of a study of the blood cells in American troops incidental to complete physical examination made at intervals during residence in the Philippines. He found a marked increase in the relative and absolute number of mononuclear blood units, the increase being at the expense of the polymorphonuclear (having nuclei of many forms) leucocytes. There was no marked change in the total white-cell count. Chamberlain (116) later confirmed and extended the findings of Wickline. Murphy and Sturm (117) pointed out the large number of lymphocytes found in the circulation apparently in the process of an amitotic (direct-cell) division. They said that after heating there is a large increase in what appears to be normal circulating lymphocytes of both the large and small type, but that it is impossible to say where they come from, although probably from stimulation of the lymphoid centers. They (117) stated also that most biologists consider that amitotic division is a degenerative process and doubt the possibility of the development of the cells into normal functioning. According to Nakahara (118) a striking number of mitotic figures have been observed in the germinal center of the spleen and lymph glands during the regeneration of the cellular elements of these organs after the destructive effect of heat. This enhanced cell proliferation is interpreted as more than compensating for the degenerated cells because of the subsequent enlargement of the organs. It has also been pointed out that the characteristic decrease in the number of lymphocytes immediately after the heat treatment is always accompanied by an extensive cell degeneration in spleen and lymph glands at the corresponding period. Upon this basis it seems evident that the pronounced lymphocytosis induced

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by means of heat treatment of the animal is due, at least in part, to the enhanced proliferative activity of germinal centers in the spleen and lymph glands, reacting to the destructive effect of heat upon lymphoid cells.

A statement regarding the spleen as a reservoir of red blood corpuscles made by Barcroft (119) in 1925 is interesting in this connection. While making a trip to the Andes in 1921 to study the alterations in the hemoglobin of the blood caused by high altitudes, Barcroft (119) and two associates were much disconcerted to note that the volume of their blood increased as they traveled south through the Carribean Sea. The curve of blood volume ran almost paralled to that of the mean temperature of the ship cabins, rising as they approached the tropical heat of Central America and falling as they entered the cooler Humbolt current on the west coast of South America. Later tests confirmed their conclusion that this was due to rise in temperature. As large cutaneous vascular areas are opened, in response to heat, to fill them the blood must come from elsewhere, and as "elsewhere" may have need of it, Barcroft (119) was led to ask whence came this outpouring of hemoglobin. From extensive experiments with the effects on the spleen of carbon monoxide, hemorrhage, and exercise he concluded that the spleen is a storehouse for red blood corpuscles outside the circulation and that the blood should be regarded as a physiologic variable that is adjusted to the work required of it and to the size of the vascular "bed" that it occupies; and that the spleen is a definite part of the vascular system, being, in fact, a reservoir of corpuscles at once fitted by its reticulum (net work of cells) to detain them and by its musculature to expel them when required to do so.

Moss's investigations (120) among miners led him to conclude that during work in high temperatures some of the men suffered from a great shortage of chlorides in the blood caused by a combination of excessive sweating and drinking of water, with attacks of "cramps" resulting. He did not feel that the sweating alone could be responsible for the shortage, since the tendency would be toward a concentration of chloride in the blood, but thought that the excessive drinking of water by miners, due probably to the dryness of the mouth and throat, tended to dilute the blood until in some of the men examined the excretion of chlorides by the kidneys showed a very marked decrease from normal despite the enormous excess of urine passed. To relieve "cramps" and also fatigue, Moss recommended the addition of salt to the water drunk by the miners.

Heilman and Montgomery (87) observed that pathological changes in the blood of several types of heat-cramp victims differed only in degree. The mildest cases showed a 2-percent reduction in plasma chlorides and the severest case a 17-percent reduction below the accepted normal minimal value. They believe that this disturbance in salt balance is responsible, in part, for the development of cramps. There was a marked apparent increase in the number of red blood corpuscles, especially in the heat-cramp cases, owing to the increased concentration of blood caused by the great outpouring of fluid. In cases that developed muscle crampsthe blood sugar remained normal or nearly normal. Examination of blood in heat-retention cases revealed little variation from that of the controls.

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Heilman and Montgomery (87) found depleted blood sugar and dehydration in heat-exhaustion cases obviously out of proportion to the diminished plasma chloride and concluded that the administration of glucose in more severe cases is indicated. They cite the benefits derived from the use of jelly drops (containing approximately equal parts of glucose and granulated sugar) in the works of the Allegheny Steel Co. After the introduction of the gum drops, cases of heat exhaustion decreased in number from 326 in 1928 to 67 in 1935.

In patients suffering from severe heat cramps Talbot (86) found changes in the concentration of the constituents of the blood as great as may be observed in the terminal stages of several diseases that are associated with profound disturbance of acid-base equilibrium. These changes were accompanied by diminution in concentration of plasma sodium and chloride. Injection intravenously of a physiologic saline solution was followed by subsidence of cramps and alleviation of pain in all patients.

In moderate heat cramps the changes in blood were similar to those observed in cases of severe heat cramps, but there was less deviation from normal in most cases. Various methods of treatment were ineffective, with no relief for 5 to 24 hours. Saline solution was given intravenously to two patients with immediate benefit.

Variation from normal in the constituents of the blood was not great in patients suffering from heat prostration. The investigators consider this observation as most important for the chemical differentiation from heat cramps. It was believed that these patients were not suffering from salt depletion. One was given Locke's solution (sodium, calcium, and potassium chloride, sodium bicarbonate, and glucose) without noticeable effect. Their findings on blood sugar in heat-prostration cases do not agree with those of Heilman and Montgomery (87), although they state that administration of 100 cc. of 50-percent glucose in 500 cc. of physiologic saline solution gave prompt relief in one case of mild heat cramps. In severe cases of heat cramp administration of glucose, adrenalin chloride, morphine sulfate, and calcium chloride did not relieve the muscle cramps during several hours, but injection of 900 cc. of physiologic saline solution was followed with all patients, by subsidence of cramps and alleviation of pain.

In cases of heat pyrexia the concentration of plasma chloride was normal. Talbot (86) concludes that heat pyrexia is not associated with depletion of body fluids and salts.

It would appear from the study by Talbot and coworkers (86) that salt would be advantageous only in the prevention and treatment of heat cramps, although they state that it is possible that certain other disorders due to heat may be prevented by salting the drinking water, as it is reasonable to suppose that the organism benefits by the maintenance of a normal internal environment.

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Lehmann and Szakall (121) were able to separate the symptoms caused by heat training from those due to lack of chloride. A young worker unaccustomed to heat was given 4 grams of chloride during a preparatory training period. He showed a general decline in health, increase in pulse rate, headache, and a feeling of weakness. After a gradual increase of salt he did good work on 10 to 12 grams daily. The authors attribute this increase primarily to the effect of the training rather than to the increased chloride intake. They found that impoverishing the chloride concentration affects the muscles rather favorably and increases capacity for work, but in untrained persons the falling concentration of blood damages the stimulating system of the heart as well as causing severe general symptoms, and may produce serious injuries when unexpectedly high performances are required of the nonadapted organism. Drinking salt water therefore is recommended.

According to Mayer (122) it seems possible that death from high temperature may be due to the accumulation of acid, possibly H_2CO_3 (carbonic acid dissolved in water), in the tissues, the acid being related to the rate of metabolism of the tissues; animals of the same class having a high rate of metabolism (as measured by oxygen consumption) are more sensitive to heat and to carbon dioxide than are those having a low rate of metabolism.

Lee (123) quotes Levene as having found that the blood serum as well as the urine of patients suffering from sunstroke was acutely toxic to rabbit Although he was unable to demonstrate any increase in nitrogen metabolism, he concluded that the symptoms of sunstroke result from autointoxication due to pathological decomposition of tissue. He quotes Van Bieson's description of pathological changes in the nerve cells of the brain and spinal cord that are similar to those produced by poisons, such as other autointoxicants, bacterial toxins, alcohol, and lead. Other investigators have found that when body temperature has been raised experimentally or in insulation the alkalinity and coagulability of the blood may be diminished. He mentions also that concentration of the blood, destruction of red corpuscles, and hemoglobinemia (abnormal presence of hemoglobin in blood plasma) were observ

As a result of observations made on board ships in the damp heat of summer on the Persian Gulf, Mitchell (124) concluded that damp heat of itself frequently produced an alteration in the blood visible only as anemia, and that this alteration was responsible primarily for difficulties experienced in the treatment of other conditions.

According to Bazett (125), in an analysis of the effects of heat on blood volume and circulation it is necessary to distinguish the parts played by local dilatation in the cutaneous vessels with its accompanying local increases in the rate of flow, capillary pressure, and fluid transudation; compensatory reduction of the vascular bed in areas other than the skin, which allows dilation in the cutaneous vessels even when the blood volume i unchanged or reduced; increases in blood volume on exposure to heat, which forms an alternative method of compensation in lieu of vasoconstrictions; a alterations in cardiac output.

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Bazett (125) describes an experiment on two subjects under the following conditions:

> In an experiment started December 26 and lasting to January 2, two subjects entered the room kept at a "normal" temperature of 23.6° C. (74.5° F.) in the daytime and at 22° C. (71.6° F.) at night. After a day at these levels, the temperatures were raised to 32.5° C. (90° F.) during the daytime and 31° C. (88° F.) at night. The humidity was maintained at approximately 36 percent. The blood volume increased 6 percent in 1 day, 10 percent in 2 days, and 25 percent in 5 days and showed an ultimate increase of over 1 liter in each subject. Even so, the volumes were still below the summer maxima observed in these subjects.
>
> Not only was there an increase in blood volume, but with this increase there also developed a greater stability of cardiovascular adjustments. Thus, in one subject the standing pulse rate was at first much more rapid than under control conditions, and the difference between lying and standing pulse rates was exaggerated. As adaptation developed, the standing pulse rate returned to its normal value, and the increase in pulse rate on standing was reduced even after 1 day's exposure to heat. The diastolic pressure observed when the subjects were lying down tended to rise progressively in both subjects. Entirely similar changes in both lying and standing pulse rates and in diastolic pressure in the lying position were observed in data obtained on one of these subjects and on a third subject in 1933 at different times of the year. The cardiovascular adjustments which developed in subjects after a stay of several days in a hot room resemble closely those found in the summer.
>
> Not only is the capacity of adjusting to standing improved but the capacity to withstand dehydration by heat with less disability is also developed. It has been shown by Vernon and Warner that subjects are able to do light work in rooms at a high temperature with less change in rectal temperature, less change in pulse rate, and somewhat less fatigue in the summer than in the winter. Such indications of greater fitness may well depend also on alterations in blood volume.
>
> For full efficiency the total amount of red blood cells must also be increased. In the aforementioned hot-room experiment both subjects had begun to increase their red cells at the end of 5 days, but in neither subject was the increase attained proportional to the increase in blood volume. The hemoglobin percentage was therefore reduced, a change not seen in Barcroft's subjects with longer exposure to heat in the tropics. In the aforementioned experiment evidence was obtained, though indirect and incomplete at the present time, that a temporary cooling of a subject for 30 hours might reverse the blood volume change and return it temporarily to normal, even though the subject returned to warm conditions. With the return to normal blood volume,

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cardiovascular adaptation to the hot conditions was lost. To obtain the beneficial effects of this mode of adaptation, it would seem essential to have the temperature maintained steadily at a high level.

Effect on the Skin

The skin is the principal seat of the sense of touch and furnishes a protective covering for the deeper tissues (121). The sensory nerves of the skin communicate four different qualities of sensation - pressure, warmth, cold, and pain. Head and Rivers (102) have classified the cutaneous senses into two systems of sensory fibers - one conveying sensations of pain and extreme changes in temperature, the other responding to stimulations by light pressures and small differences in temperature between 26° and 37° C. The cutaneous senses (102) are not distributed uniformly over the whole skin but are present in discrete points or spots. The temperature of the skin, whatever it may be, forms the zero line; contact with an object of a higher temperature stimulates only the warm spots, while one of a lower temperature acts upon the cold spots (102).

According to Hicks and O'Connor (126) the average skin temperature depends mainly on atmospheric temperature and is the most satisfactory index of "cooling power." They conclude from their experiments that the actual value of the skin temperature at any site depends on the mass of vascular material underlying it and the extent of its insulation by fat.

In an article on the human hand, which he calls a truly marvelous organ, Hill (127) refers to the wonderful blood supply with which the hands are provided. This blood flow to the skin, primarily intended to supply nourishment and warmth and remove the waste products of muscular activity, it now develops has an additional function of great importance. He makes the following statement regarding it:

> Dr. Charles Sheard, director of the division of physics and biophysical research of the Mayo Foundation, related to the engineers gathered at St. Louis last January some interesting developments in his research work at Rochester on the skin temperature of the hands under various conditions.
>
> It has been observed by other investigators that the temperature of the hands and feet varies over a much wider range than does that of other body surfaces. The writer has seen the temperature of the fingers rise 9° F. in a few minutes while the subject smoked a cigarette, the temperature and humidity of the room remaining constant. Dr. Sheard has noted a temperature rise of 25° F. of fingers in a period of 2 hours after the subject has taken food. Even with the subject quiet, without food or other disturbing influences, in a room where the temperature and humidity are constant, the skin temperature of the fingers wanders back and forth over a range of 8° or 10° F. while the skin temperature of the head and trunk varies only a degree or so, if at all.

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The obvious conclusion, Dr. Sheard points out, is that the hands and feet, particularly the hands, are the principal temperature-controlling organs of the body. The relatively large surface of the hands and wrists makes them, like small radiators, well-adapted to so function, forming also, as they do, about 70 percent of the exposed surface when the body is clothed.

An interesting sidelight on this new conception of our comfort mechanism is the fact that we are not conscious of comparatively wide variations in the skin temperature of our hands; our friends tell us that our hands are hot or cold before we realize it ourselves. This fact explains why the comfort zone on a psychrometric chart is so broad and its boundaries so indeterminate.

Engineers have long felt that the medical profession has underestimated the importance of our air environment as it affects comfort and health, and doctors have long known that the engineers underestimate the difficulties and complications involved in pinning down the phenomena of living organisms to definite mathematical lines and curves. The engineer likes to solve his problems logically and directly. He asks the subject if he is comfortable and plots a point and later a curve from the replies elicited. The physiologist believes that the correct procedure is somewhat more complicated. The two viewpoints must be completely coordinated before a true picture appears.

According to Sewall (128), the temperature nerves of the skin are specific sense organs for appreciation of variations of temperature and humidity through which a wide range of metabolic actions in the body is regulated. It is through the moving air of the open that the temperature nerves find their most salutary stimulus and induce metabolisms characteristic of highest machine efficiency. The physiologic difference between "open" and "closed" air depends partly or wholly on differences in the stimulation of the temperature nerves of the skin under the two conditions.

Apart from voluntary modification of his surface by posture and of his insulation, heat loss in man depends upon the temperature of his skin and the rate at which water is evaporated from it (129). Rubner (quoted by Martin (129) estimated that a man comfortably clothed and sedentary in a room at 15° C., the air of which is 50-percent-saturated with water, loses 44 percent of his total heat dissipation by radiation, 31 percent by convection, and 20 percent by evaporation from lungs and skin. The proportion is different if the surrounding temperature appraches or exceeds the temperature of the skin and if the sun shines on him; under these conditions, loss by radiation and convection is minimized or heat transferrence by them is reversed, leaving only evaporation available.

Exposure to abnormal air temperatures affects the excretion of water and carbon dioxide from the skin, as well as secretions from the sweat and sebaceous glands.

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Excretion of Water

It is estimated (102) that the skin and lungs of a healthy person give off together about 550 grains of moisture an hour - enough to raise the relative humidity of the vapor in 380 cubic feet at 60° F. from 75 percent to complete saturation.

Experiments conducted at the Mining Research Laboratory of Birmingham University (130) reveal that loss of water from the skin may occur in two ways - by evaporation of water that has permeated through the general surface of the skin (osmosis or diffusion) and by evaporation or trickling down of sweat secreted by the sweat glands.

Loss of water by osmosis. - In addition to the well-known fact that with rise in temperature of air the loss of water through the skin increases rapidly, it was discovered (130) that during rest in air of ordinary dryness virtually all of the loss was osmotic until the air temperature reached 85° F., and most of it was osmotic until the air temperature was well above body temperature; also, the osmotic loss increased enormously with rise in air temperature short of the point at which the skin became wet. With an air temperature of 101° F., the osmotic loss was 117 grams an hour. According to Whitehouse (130) evaporation of this amount of water from the skin would absorb 68 kilogram-calories of heat an hour, or 1,630 in 24 hours, which corresponds to about the heat produced in the ordinary resting metabo of a man. Osmotic loss of water through the skin therefore plays an import part in regulation of body temperature. Whitehouse describes the process a follows:

> As the air-temperature rises, loss of heat from the skin by conduction and radiation tends to diminish, in spite of increased skin-circulation; but this is compensated for by increased osmotic loss of water, until a point is reached where osmotic loss is supplemented by sweating, which is at first insensible. With further rise of temperature, the sweating increases until the whole skin becomes wet, so that osmotic loss is entirely prevented. If the sweat present visibly on the skin became very concentrated, however, as tends to occur in dry or rapidly moving air, osmotic loss of water could still occur to an appreciable extent.
>
> There is nothing surprising in the fact that osmotic loss of water increases so markedly with air-temperature. As the air-temperature rises, the rate of skin-circulation certainly increases greatly, doubtless in consequence of theopening up of large numbers of capillaries which were previously closed. The vapor pressure of water in the blood passing through the skin increases, also, in consequence of the blood being warmer. Thus both increase in the number of open skin-capillaries and rise in vapor pressure in the blood will contribute to the great increase in osmotic loss of water as the air-temperature rises, though the experiments referred to below on the rate of absorption of oxygen through the skin, indicate that the former factor is by far the more important one.

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It will be seen that the effect of raising the dew-point of the air was not very marked before the dew-point of air saturated at body-temperature was approached. It would seem that raising the dew-point tends to raise the skin-temperature, and that this increases the osmotic loss by nearly as much as raising the dew-point diminishes its.

In addition to the effect of air-temperature on the osmotic passage of moisture, it would be expected that muscular exertion in cool air would have a similar effect, since it leads to increased circulation and rise in temperature of the skin. It will be seen that this was the case, and it is evident that osmotic passage of water through the skin plays an important part in the regulation of body-temperature during muscular work, as well as during rest.

It seems quite evident from this whole series of experiments that osmotic loss of water through the skin is under the same physiological control as the skin-circulation. The manner of this control is intelligible as being part of the maintenance of body-temperature; and cooling from osmotic loss of water adds greatly to the influence of varying skin-circulation in adjusting heat-loss from the body to either variations in surrounding temperature, or variations in heat-production in the body.

The experiments on the relation of warmth to osmotic transfer through the skin have had to be made with the skin naked, but they certainly apply also to conditions in which the skin is clothed, although with clothing the influence of warmth will appear at a much lower air-temperature. Provided, however, that moisture can pass freely through clothing, and thence to the atmosphere, osmotic loss of water will play just as important a physiological part with clothing on as with it off.

Loss of water through the sweat glands. - The average quantity secreted in 24 hours by the sweat glands is said (102) to range between 700 and 900 grams.

According to Martin (129) a man at rest produces about 1.2 large calories a minute, so he must, under these atmospheric conditions, evaporate at least 2 cc. of water a minute (each gram of water evaporated absorbs 585 small calories), or 120 cc. an hour, even under the most advantageous circumstances for deriving all the heat required for evaporation from the body. With fairly strenuous work the heat produced will rise to 5 or 6 large calories, requiring a minimum of 600 cc. (approximately a pint) to be evaporated per hour, or his body temperature must rise. If he has to work in the sun surrounded by objects hotter than his body he will need to evaporate considerably more, possibly twice as much.

Schierbeck (131) estimated from his experiments that the amount of moisture secreted by the skin in calculated perspiration was at least 1,500 grams daily.

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Tests on sheet-mill crews at the plant of the Youngstown Sheet & Tube Co. (111) revealed that the fluid loss through the skin was as much as 20 or more pounds (2 1/2 gallons) of sweat during the 8-hour work period. The men averaged about 15 pounds of fluid intake during the work period, and on plain drinking water ended the day with a loss in weight averaging 5.6 pounds. When the men drank water having a salt content of 0.1 percent (about 1 level teaspoon to the gallon) the average loss was 1 1/2 pounds.

It is difficult to determine precisely the chemical composition of sweat as generally it is mixed with the sebaceous secretion. When produced in quantity under the action of temperature or muscular work, it usually is distinctly acid. High temperature does not excite the sweat glands immediately, but through intervention of the central nervous system. The existence of physiological centers controlling the secretory fibers is implied, but the exact location of the sweat center or centers has not been determined satisfactorily (102).

The suppression of sweat constantly associated with heat hyperpyrexia (high fever), which usually occurs many hours before the onset of the hyperpyrexia, is believed by Hearne (132) to be due to paralysis of the sweat glands. From experimental studies, Heidenhain (133) concluded that the diminution in the secretion of sweat from the injection of atropine (which is known to increase the liability to an attack of hyperpyrexia) was not due entirely to paralysis of the secretory nerve endings but also to decrease in the permeability of the vessel walls. By analogy Allen (134) concluded that the suppression of sweat in heat hyperpyrexia is due to relative impermeability of the blood-vessel walls.

According to Martin (129), the mechanism of thermotaxis (regulation of heat in the body) consists of afferent neurons (nerve cells that conduct a nervous impulse from a receptor to a center) with special terminations in the skin that are sensitive to temperature; efferent neurons (nerve cells that conduct a nervous impulse from a center to an organ of response) that activate various mechanisms whereby heat loss or heat production is varied; and a central coordinating machinery. The efferent nerves concerned with heat loss are the nerves to the vessels of the skin, to the sweat glands, and to the erector muscles of the hairs. The nerve paths along which the impulses pass that modify heat production are extensive and include the nerve supply to the musculature and all the active tissues of the body as well as the endocrine glands.

Excretion of carbon dioxide

Schierbeck (131) found by experimentation that a subject at complete rest exposed to an air temperature of 30° to 33° C. excreted about 35 to 40 mg. carbon dioxide an hour. At a temperature higher than 33° the excretion of carbon dioxide suddenly began to increase, until at 34° it was twice as much. There appeared to be a critical point between 33° and 34° at which carbon dioxide excretion increased greatly, at the same temperature at which sweat broke out on the surface of the skin. He concluded that the excretion of carbon dioxide from the skin was not less than 8 grams in 24 hours.

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Willebrand (135) found that the secretion of carbon dioxide through the skin remained unchanged during complete rest at 20° to about 33° C. - about 7 or 8 grams in 24 hours; when, however, the temperature reached the point at which sweat appeared (about 33° C.), the amount of CO_2 excretion suddenly increased three or four times. Willebrand stated that he had found no explanation of the manner of secretion of CO_2 through the skin but assumed that the CO_2 present in the blood is diffused through the fine capillary vessels and then through the epithelium.

According to Pemberton (136), who studied for some years the changes accruing from the exposure of the body to external heat in the form of radiation from electric lamps, exposure of the body to the therapeutic application of external heat results in a heightened blood flow, an increased metabolism, and in the elimination of acids, chiefly carbon dioxide, which escapes through the lungs, urine, and sweat, in amount in the order of means of escape named. This leaves an excess of alkali in the blood, which then changes its reaction, becoming more alkaline. In the compensatory effort to meet this situation the excess of alkali is eliminated through the sweat and urine. The profound nature of the changes introduced by these measures is clearly indicated, and explanation is afforded of some of the painful consequences that follow their uncritical use. If carried to extremes, tetany may result. The available evidence indicates that part of the benefit of the sweat process in some forms of nephritis is due to loss of acid substances from the body, with consequent benefit to the acidosis frequently accompanying renal disease.

Skin affections

The soaking of the skin due to working in hot places lowers the vitality and facilitates the entry of staphylococcus, which, according to Fisher (137), is a well-known cause of prepatellar cellulitis (miners' beat knee). Fisher (137) investigated conditions at several collieries in Great Britain where it was reported that the miners were afflicted with boils. He found boils most prevalent in mines where the temperature and humidity were high (around 93° dry-bulb and 75° or more wet-bulb). He observed also that boils occurred more often on men who sweated profusely and whose bodies were covered with a fine film of wet coal dust; however, he did not think the composition of the coal had any influence, and no pathological microorganism was found. Boils were reported at only one mine having pithead baths, and then only a very few occurred. Pithead baths apparently are a valuable preventive. Fisher (137) concluded from his investigation that, aside from individual predisposition to them, the cause of boils underground is high wet-bulb temperature (75° or more), which provides suitable conditions (warmth and moisture) for the vitality of the organism and by opening the sweat glands and hair follicles facilitates the entry of the staphylococcus.

Fisher (137) considered it important to determine the location of the first boil. In many instances it could be traced to a slight scratch or injury. Ten cases started on the knee, 8 of which might have been diagnosed as "miners' knee." In other cases the original focus was located as follows:

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Back, 9; elbow and forearm, 9; lower third of leg, 7; fingers, 5; wrists, 5, 3 of them in surface workers; toe, 1; buttock, 3; face, 4; axilla, 2; shoulderblade, 1; neck, 1; ankle, 1; abdomen, 1; and thigh, 4.

It has been suggested that the change from the normal reaction of the skin to a neutral or even alkaline reaction due to greatly increased sweating for some time may be an important factor in the skin infections of these exposed to a hot working environment. In this connection, Whitehouse (130) called attention to the interesting fact that treatment of certain cases of skin infection with acid solutions, such as alcoholic hydrochloric acid solution, was successful.

Effect on the Respiratory System

With increasing humidity, it is noted that at high temperatures the respiration frequency increases so much that care must be taken not to expose oneself for a long time to a very high temperature. The connection of the increased decomposition of foodstuffs with the increased work in breathing is sufficiently expressed in the increase of total heat production, which from 69.3 calories at 9.0 percent relative humidity reaches 70.9 calories at 16 percent and 75.5 at 30 percent relative humidity (138). Haldane (139) found that hypernea was not noticeable until the rectal temperature exceeded 102° F.; at 103° it was marked during muscular work, and distinctly noticeable during rest. According to Sihler (140) respirations grow more shallow instead of deeper in warm moist air. In the case of lower animals, rates of 300 or more a minute have been observed with the thermometer 100° to 104° in the shade. McConnell, Houghton, and Yagloglou (141) report that in experiments conducted by them with subjects at rest the respiratory rate did not increase noticeably during the test, except in extreme conditions. In moderately warm experiments, the respiratory rate frequently diminishes. In extreme conditions the air is too hot to be inhaled through the nostrils, and oral breathing is necessary. The subject apparently seeks relief through respiration, but on inhalation he finds no relief and immediately exhales, so that the result is a series of short, irregular respirations. It is doubtful whether ventilation of the lungs is increased under these conditions In tests where the air is not too hot and permits nasal breathing, all subjects were able to hold their breath longer than in cooler atmospheres. In extreme conditions, if the subject's attention is called to his rapid breathing and he is asked to breathe slower he invariably does so. On the other hand, on leaving the test chamber the respirations increased in depth and number; this gives a certain amount of relief, and the subject continues to breathe rapidly and deeply until he is relieved of the symptoms of discomfort he has just experienced.

Dérobert (142) states that while man loses 75 to 85 percent of his heat by way of the skin, the loss by evaporation of water from the lungs is only about 14 percent. Through studies in an artificial mine, Bonnardel and Langier (143) found that in repose the ratio between the water lost by respiration and that lost through the skin (evaporatory quotient of Boussaguet) was about 40 percent. During work it fell to 12 to 16 percent; ventilation of 2 to 3 meters per second in a dry atmosphere may cause this quotient to fall below 2 percent. They stated, however, that on the other hand any

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deviation in temperature between the dry thermometer and the wet thermometer of less than 4° when the wet thermometer is above 24° C. indicates a surrounding atmosphere incompatible with physiological working conditions.

Osborne (144) stated that to the list of agents that excite the respiratory center must be added a high environmental temperature. Ventilation of the lung is markedly increased when the air temperature is high. There is some indication that with rising shade temperatures (wet- and dry-bulb) the respiratory quotient rises and approaches unity. His only conjecture as to the cause was the heating of the carotid blood in its passage up the neck. It is interesting in this connection that Moorhouse (114) observed an increase in respiratory ventilation as a result of warming the brain by heating the carotid blood.

In experiments on dogs, Rubner (138) found that the same quantity of water was evaporated from the animals in spite of increased moisture in the air. He concluded that this was due to regulation of breathing, as with increased humidity at high temperature it was observed that respiration increased so much in frequency as to be dangerous for long exposure.

Eröss (145) found that the number of respirations did not exceed normal in premature and marantic (emaciated, feeble) infants exposed to high temperatures; but in well-developed, healthy infants respiration was accelerated, and this acceleration was accompanied by dyspnea (shortness of breath), which disappeared when the heat was removed. Shortness of breath is attributed to affection of the nervous system, as it is not present in sickness where there is fever if the heart and respiratory organs are not affected. Haldane (105) observed dyspnea, especially on exertion, during exposure to abnormal temperature and humidity. Boycott and Haldane (146) explained the activity of the respiratory center, as due to the varied stimulation of the face, nose, etc., by hot and cold air as well as by the carbon dioxide pressure in its cells. Experiments by Thompson (147) on guinea pigs and mice showed that the higher the temperature the lower the percentage of carbon dioxide in the exhaled air.

Hyperventilation was noted by Hicks, Keeton, and Glickman (148) as a response of some subjects to a hot environment. Trained subjects exposed to very high effective temperatures breathe out per unit time a great deal more air than at lower ranges. This response often is given at lower temperatures by nervous, untrained persons and is a common source of error in observations on untrained subjects against which suitable precautions must be taken; it was observed when the temperature was rising.

Hicks and his coworkers (148) found that when hyperventilation lasted more than 2 minutes enough CO_2 was washed out of the body to give rise to symptoms of headache, nausea, weakness, giddiness, and prostration.

Effect on Nervous System

In a study of the beneficial and injurious effects of heat, Sonntag (149) found that high temperatures are powerful excitants and long exposure to moderate temperatures at first stimulates and later depresses. When the

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human body is exposed to thermal stimuli in the form of climate or hydriatic procedures, sooner or later certain symptoms appear, which range from a feeling of enervation or lassitude, as after hot applications, to collapse accompanied by hyperpyrexia, as in the thermic fever of tropical regions. Sonntag (149) arranged the causes of these symptoms into three groups: (1) Diminished oxygen supply to the central nervous system, (2) toxemia, and(3) thermal stimulation of the nerve cells. He elaborated these points as follows:

> If we immerse a part of the body in water at a temperature above that of the skin zero, a certain amount of heat loss is prevented, so that more loss must take place through the rest of the skin. The heart beats quicker so as to drive the blood more rapidly through the available skin area. These actions are correlated by the nervous system. The greater the part immersed the greater is the pulse rate, and there seems to be a definite relation between the pulse rate and the area of the skin available for cooling.
>
> The heated blood takes up less oxygen at one end of the metabolic scale and less carbon dioxide at the other, and the higher the temperature of the blood the smaller the quantity of gases absorbed. A state of thermal asphyxia is brought about. The tissues have a certain amount of intramollecular oxygen upon which they can carry on their functions for awhile and different tissues have different amounts, but the central nervous system has the least. Again, some parts of the nervous system have more than others; probably the repiratory nuclei have least of all, for they fail before the other nuclei.
>
> Some of the effects of diminution of oxygen to the nervous system are vacuolation, cloudy swelling, and intrusion. Oxygen is a source of energy and protects the cells against toxic invasion and damage. The blood supply to the nervous system is diminished when the cutaneous vessels are widely dilated in the hot bath.
>
> When the asphyxia of the cells begins the toxins have an opportunity to act. These injurious substances are both intercellular and extracellular. The intercellular are produced in greater amount than normal because heat applied to the body stimulates the cells to greater activity. The extracellular toxins, which are injurious substances in the blood and lymph, base their action on the partition between solutions and fats. Evidence has accumulated to show that sunstroke is a toxic state.
>
> The result of these actions is that the nerve cell has lowered vitality and the trophic impulses sent out are cut down. The diminution of stimuli to the muscles produces the enervated feeling which follows a hot bath or a warm climate.

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Several conditions predispose to thermal debility: Fatigue, abuse of alcohol, improper clothing, some underlying condition such as cardiovascular disease, and a poor heat-regulating mechanism which occurs in the aged and in the young child.

According to Barcroft (150) man's intellectual development and motility depend on the temperature and other factors of his internal environment remaining constant; as little as 1° of fever affects the mental processes. He states that before the heart has lost its efficiency and the respiration is more than quantitatively affected, the coherence of the mind is gone. He quotes the results of experiments by Sutton with heat as the counterpart of his own experiments with cold, as follows:

The general condition of the subject, especially the mental phenomena, seems to bear a close relationship to the rise of internal temperature. In later experiments a tolerable guess as to its height could thus be made. The marked sensation of heat felt on entering the hot room soon passed off on resting quietly and was replaced on the occurrence of free sweating by a relaxing and not unpleasant sensation of warmth. Dilatation of the vessels and relaxation of muscular tone were marked, and still more marked was the sensation of sleepiness, which oftentimes became quite overpowering. This condition, however, only existed during the stage of compensation when the body temperature was stationary or only beginning to rise gradually. The organism seems to reduce its energy to a minimum and so muscular and mental effort are practically abolished. This state lasted during these experiments for half an hour or so, for as soon as the rise of body temperature became at all definite this was associated with quite another set of sensations. Sleepiness disappeared and the complete muscular idleness passed off and was replaced by a marked and increasing irritability. The change from drowsiness to wakefulness and irritability was comparatively abrupt, and occurred quite constantly at about 99.5° F. Once the rise of rectal temperature was fairly marked (2° - 3° F.) the continuance of any employment such as reading a book or sitting in one position became intensely tiresome. For example, the attempt to learn by heart a short vocabulary of German words proved a complete failure. To remain at rest required a marked effort of will and the only approach to comfort was obtained by slowly lounging about so as continuously to change one's position. Later on the body temperature rose to over 103° F.; any irritation, however slight, became not merely tiresome, but actually annoying and trying to one's temper. This irritability - a preliminary sign of early exhaustion of the central nervous system - is thus closely associated with rise in body temperature. Immediate relief was felt on reaching the cool external temperature, and this was accompanied by a rapid fall in internal temperature 2° - 3° F. in 10 to 15 minutes.

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In experiments on the reflex excitability in the frog induced by changes of temperature, Tarchanow (151) noted the period of unrest through which the animal passed as the temperature rose and also the period of prostration that finally ensued. He called attention to the fact that since the cause of this prostration could not lie in the nerves or muscles (these were found intact), it must be sought in the brain or spinal cord.

Archangelsky (152) concluded that the loss of reflex excitability under heating is due to weakening of the spinal cord alone.

Martin (129) states that the central mechanism of thermoregulation is itself sensitive to temperature and is so organized that it discharges impulse through appropriate nerve channels according to whether its temperature rises above or falls below a predetermined level. The mechanism however, is more elaborate than this. Instead of waiting for the blood temperature to rise or fall, and meanwhile wasting calories, adjustment can be brought about reflexl from the surface. The center is connected with the nerves of temperature sense from the skin and responds with rapidity by efferent impulses that modify heat loss from the surface or perhaps by others that result in an increased or diminished production of heat. It has been suggested that such coordinated reflexes themselves could achieve homoeothermism, and the importance of the fact that the central nervous machinery is also directly sensitiv to temperature is minimized by some physiologists. Consideration, however, will show that direct sensitivity of the center is essential. A reflex mechanism to diminish heat loss and increase production when the skin cools would work progressively, and the temperature inside would rise. In fact, a rigor would occur. The reverse would happen if vasodilatation in the skin occurred in response to warmth. The skin would become progressively warmer and the body temperature would fall.

There must be some mechanism to control these reflexes as soon as they have accomplished their purpose, and it is suggested (129) that it is the direct influence of the slightly warmed or cooled blood reducing the sensiti of the appropriate parts of the central apparatus to stimulation by impulses arriving by one path or another.

Effect on Muscles

Bernard (89) believed that heat acts as a direct excitant of the muscul system of organic life but does not have the same effect on the muscular sys of animal life. His explanation follows:

> Never has it been observed that heat, for example, has the property of causing contraction of the muscles of the limbs. A dozen years ago, a Greek doctor, Dr. Calliburces, made in our laboratory some investigation upon these questions, and from this point of view he divided the muscles into two classes: The muscles which he called thermostaltic and those which he called nonthermostaltic. He recognized that the same muscular organs could be thermostaltic or nonthermostaltic according to the periods of their development at which they were considered.

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Thus the gizzard of the hen, which is directly sensitive to the action of heat at the moment of hatching, ceases to manifest this property some days after coming from the egg when this organ has entered into its final functional state.

We have already said that this exciting action of heat upon the muscular element has necessarily a limit, and, here as always, we see that that which is a vital physiological agent becomes a toxic agent when its action is pushed to the extreme. Thus, if the temperature is raised too much, the heartbeats, after becoming more and more rapid, suddenly cease. In the same way the peristaltic movements of the intestine completely cease if subjected to heat beyond a certain limit. In these cases it is death, death complete, absolute, inevitable, which seizes the muscular tissue; and, in fact, we have seen, in the case of animals killed by heat, the heart is absolutely insensible to all excitation, and finally that cadaveric rigidity takes place with prodigious rapidity. What is the cause of these phenomena? One is at the very first led to search for it as of purely chemical nature. The contractile element, fiber or cellule, whatever its form, encloses in the interior of a fine and amorphous sheath a substance always the same to which is given the name of myeline or sintonine. Might there not be produced, under the influence of heat, a modification in this myeline, a coagulation? Kuhne formerly made in our laboratory some experiments which have led to this conclusion.

It appears then very possible, or at least probable, that there is in fact a real coagulation of the myeline and that this is the cause of the death of the muscular element and of the heart in particular. The manner in which heat causes death would thus be perfectly explained. However, as some animals have been taken from the oven a few instants before the fatal moment and have not died for several hours or even several days after the experiment, it is necessary to admit that there are other serious alterations produced by heat.

The vibratile cilia, which are found in abundance upon certain mucous membranes, are excited by heat in a manner similar to the effect of heat on the contractile system of the heart and the intestines, but the movements of the cilia continue with great activity after the others have stopped.

Bernard (89) drew the following conclusion from his experiments:

Heat is an agent indispensable to the activity of life; but a moment comes in which the excess of heat acts upon the organism as a toxic agent.

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As all toxic agents, we have seen that heat attacks a single one of the essential elements of this organism, the muscular element. It is then the loss of the vital properties of this element which by producing rigidity, arrests the circulation and respiration, and causes death. This destruction of the contractile element takes place at about 37° to 39° C. with cold-blooded animals, at about 43° to 44° with mammals, and at about 48° to 50° with birds, that is to say in general at some degrees above that of the normal temperature of the animal.

Raising the temperature of human beings is unfavorable to muscular work the normal heat of the blood being the most satisfactory for it. In reflecting on the toxic nature of fatigue and the more rapid activity of certain poisons when they act on heated organisms, Patrizi (153) concluded that the toxic power of the products of fatigue also is augmented in the muscles with increased temperature. Thus the small amount of mechanical work accomplished by the muscles of man at a temperature above that of the blood and the rapid appearance of fatigue are due to the greater exigencies of the muscular tissue and to the more energetic toxicity of the waste substances engendered by fatigue.

Mills (75) has pointed out that resistance to infection is linked to ease of body heat loss and to the combustion level allowed the individual. Investigations in his laboratory revealed that mice adapted for at least 3 weeks to 90° F. and 60 percent relative humidity succumbed with only one-fourth the injected dose of organisms it took to kill those adapted to 65° F. when an intermediate-size dose was injected all from the hot room died while all from the cold room survived. These differences occurred with all factors of existence, except ease of body-heat loss, held constant.

In experiments to determine the effects of temperature and humidity on the working power of muscles, Lee and Scott (154) found that muscles taken from animals immediately after exposure to "low" (69° F. and 52 percent average humidity), "intermediate" (75° F. and 70 percent average humidity), and "high" (91° F. and 90 percent average humidity) atmospheric conditions and stimulated to exhaustion performed decreasingly less work as the temperature and humidity increased. Expressed in percentages, the figures for the duration of the working periods were: Low 100, intermediate 97, high 89. For the total amount of work performed the figures were: Low 100, intermediate 85, and high 76.

Effect on Efficiency and Working Capacity

Persons who live under a blanket of moist heat that makes body-heat loss difficult show a distinct disinclination to do work of any kind, physical or mental (75). Any effort or exertion is accompanied by corresponding increase in production of heat. According to Mills (75), ease or difficulty in losing body heat seems to play a dominant role in the existence of man and other warm-blooded animals. As heat loss becomes difficult, all body functions and general vitality are lowered, and existence tends to assume a vegetative level. On the other hand, greater ease of body-heat loss acts as a direct stimulant to the general vigor of the individual, making possible a more energetic level of existence.

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Exposure of workers to a hot, moist atmosphere has an effect on their efficiency and working capacity more or less similar to that of living in a hot, moist climate. Human energy is derived from the combustion of foodstuffs. Exposure to high temperature and humidity in the working environment in north temperate climates probably would be more likely to cause acute effects in the worker than in the climates where he is exposed to high temperatures all the time. Dreosti (155) found that natives from tropical areas were more "acclimatized" and therefore less affected by heat-tolerance tests than other natives. Ogle and Mills (156) found that animals adapted to constant heat to a considerable extent lose their ability to produce heat and to keep warm under chilling emergencies; those adapted to a cooler environment are more able to meet chilling conditions by increased production of heat but succumb to excessive heat much more readily than those adapted to constant warmth; a few hours' cooling each day counteracts the depressive effects of heat and keeps the metabolism as responsive to chilling as a constantly cool environment; and animals adapted to a cold or changeable environment rapidly exhaust their glycogen supplies when chilled, while combustion is much slower in those exposed to constant heat. In commenting on the low working efficiency of the human body compared with the combustion rate, Mills(75) states:

> Body efficiency declines in proportion as the energy level, and combustion rate increase. The more active and energetic a person is, the more effort he will expend in performing a given task. In other words, the tropical native can accomplish more work on a loaf of bread as fuel than can the energetic northerner. He will take a longer time to do the job, but as a machine he is more efficient.

As a result of studies in cotton-weaving sheds Legge (157) concluded that powers of accommodation of all workers must be taxed when the wet bulb rises above 70° F. Continuous work for long periods in a warm, moist atmosphere may be injurious to health, but the ill effects are felt definitely only when the wet-bulb temperature reaches about 75°.

Haldane (139) considered the wet-bulb temperature to be the measure of atmospheric conditions suitable for efficiency of workers. He set the limit for men resting and lightly clad at 88° F. wet bulb or 93° F. in air moving at 170 feet a minute. He believed that the limit for active work was 78° F. wet bulb in still air and 85° F. in air moving 135 feet a minute; that at 80° wet bulb the work of a miner decreased; that at 85° hard work was virtually impossible; and that beyond about 88° F. it was impracticable for unacclimated persons to stay in such air for long periods.

According to Atkinson (158), high relative humidity is one of the biggest bugbears in deep, level mines such as the City Deep, and attention is being devoted to the separation of the wet- and dry-bulb temperatures of the air in its journey throughout the mine. He stated that the efficiency of the underground worker is in direct proportion to the separation of wet- and dry-bulb temperatures of the main ventilating currents in stopes and other working places. The critical wet-bulb temperature at which man is likely to collapse

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is said to be 93°. Spalding and Parker (159) state that the critical stage in a mine that is being deepened and whose bottom temperatures, therefore, are rising slowly is reached suddenly, and an increase of 1° in wet-bulb temperature makes the difference between being just able to carry on and complete failure to do so.

Observations by Bedford, Vernon, and Warner (160) on the working capacity of coal miners in relation to atmospheric conditions do not agree with Haldane conclusions regarding the influence of the wet-bulb temperature on the limit of endurance at high atmospheric temperatures. They measured the influence of atmospheric conditions on the working capacity of 304 miners by noting the duration of rest pauses taken from work. The amount of time taken for rest was more closely associated with the dry-bulb factor than with the wet. They concluded that neither the relative nor the absolute humidity of the air seems to have any definite effect on the amount of time taken for rests when the dry kata cooling power is kept constant.

The conclusion regarding the effect or lack of effect on rest pauses of workers is borne out by the following observation of Bureau of Mines investigators in hot mines (161). In a stope where the air was not quite saturated (91.5° wet bulb and 91.75° dry bulb) but was absolutely stagnant, the workers were accustomed to going to the level below to cool off after working in the stope for 15 to 20 minutes and returning to work after resting for 15 to 30 minutes. A small fan driven by compressed air was introduced by the investigators to give local movement to about 5,000 cubic feet of air per minute, recirculating the air in the place essentially as is done by the ordinary office fan; the velocity was more than 3,000 linear feet a minute at the fan delivery, diminishing to a few hundred feet a minute at a point 25 or 30 feet from the fan. So great was the improvement that the stope workers not only discontinued the practice of going down to the level to cool but remained at work in the stope virtually continuously. Other investigations of the Bureau of Mines in cooperation with the Society of Heating and Ventilating Engineers (162) indicate that sensible and latent heat loss is the function of dry-bulb temperature and is affected only slightly by relative humidity, except at extreme temperatures.

In the studies made by the Bureau of Mines (161), ladder climbing (120 feet up and the same distance down in 5 minutes, with a rest of 20 to 25 minutes between climbs) in still, almost saturated air at 75° F. was pronounced "child's play" by the four subjects engaged in it, and there was little if any reaction after an hour's work. However, when it was tried for an hour in still, virtually saturated air at 80° F. the physical effort as we as the physiological effect was perceptibly greater; when 85° F. was reached the ladder climbing became real work, and at 90° F. it was impossible to endure the usual rate of climbing for a full hour.

Talbot (163) considers relative humidity less important than temperatur and states that it is a misbelief that cramps occur only in an atmosphere wi a high relative humidity. Most cases have been observed in men working in a humid atmosphere, because most hot jobs are associated with high relative

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humidity. However, during the building of Boulder Dam at the time patients with cramps were admitted to the hospital the relative humidity never exceeded 25 percent, and there was no conclusive evidence that the incidence of heat prostration would have been greater in a very humid atmosphere.

According to Purdy (164), records collected by Bruce revealed that the comfortable and invigorating conditions of temperature in relation to moisture in the air are indicated by the dew point rather than by any mere indication of the wet bulb or of the dry bulb alone.

He found that a wet-bulb temperature of 70° or 75° is not oppressive when the dry bulb is 80° or 90°, but when the air is fully saturated and there is no evaporation - that is to say, when the dry- and wet-bulb temperatures are identical - a temperature of 70° is very oppressive and a temperature of 75° is almost unendurable, most muggy and oppressive. He found that a wet- and dry-bulb thermometer based upon a constant dew point gave comfortable and desirable conditions at all dry-bulb temperatures in New South Wales. So long as the dew point did not rise much above 62° F. conditions were not unpleasant. Even with a very high dry-bulb temperature bodily vigor was not impaired. With a dry bulb of 111° and a wet bulb of 82°, but with the dew point only 66°, hard work was done without discomfort, although the air was burning hot, whereas with a dry bulb of only 77° and a wet bulb of 75°, but with the dew point 73.5°, conditions were depressing.

The table of permissible dry- and wet-bulb temperatures in the New South Wales Factories Act of 1909, as fixed by Bruce, was based upon a minimum dew point of 57° and a maximum of 67°. This gives a mean dew point of 62° F., at which temperature saturated air is neither muggy nor chilly. When the dew point is 70° to 75° exertion becomes difficult, but with the dew point near 62°, even with high wet- and dry-bulb temperatures, work can be carried on without inconvenience.

McIntyre (165) reports that tests on a group of 23,000 miners who had worked 2 to 6 years in collieries of Great Britain revealed that men working at a dry-bulb temperature of 70° F. lost 3 percent of the time from sickness; at temperatures between 70° and 79° F. the time lost was 4.5 percent; and at temperatures exceeding 80° F. the time lost rose to 5 percent. When the data were based upon wet-bulb temperatures the time lost at temperatures below 66° F. was 3 percent, between 66° and 69° F. it was 4.2 percent, and above 70° F. it was 5 percent.

In addition to the great reduction in efficiency of the human machine owing to the difficulty of keeping down the body temperature during work in high wet-bulb temperature, Briggs (166) suggested as a possible cause the impairment by the hot, damp air of the passage of oxygen from the air in the lungs into the blood. He mentioned the following experience as indicating this:

> A rescue-brigade were exercising with breathing-apparatus in a road in the Niddrie Colliery. A steam-pipe ran along the road; some steam was escaping, bringing the air to saturation-point at a temperature of 85° F. After more than an hour's light

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work, a halt was called, and the Instructor (Mr. D. Davidson) advised the men to take out their mouthpieces and rest. They did so, but very soon slipped them back again, one by one. They preferred to breathe air from the apparatus - which by that time would also be saturated and of at least as high a temperature as the outer atmosphere - rather than fresh air from the road. The air of the apparatus would contain 70 or 80 percent of oxygen; it would, therefore, be more comfortable to inhale than normal saturated air at this high temperature if there were any difficulty in getting a proper oxygen-supply from the latter. This seems to be a point calling for investigation.

There is evidence that those who are used to hot, damp air can do hard work at temperatures exceeding 80° F. Mr. Eric Davies has recorded that, in a fairly good air-current in the Morro Velho mine, Brazil, regular work is proceeding at a wet-bulb temperature of 84° or 85° F. On occasions it is higher; in one instance, where hard labor such as loading and pushing trams was going on, it was 92.5°.

Again, Mr. J. S. Hayes has described in a recent paper how coal-mining is proceeding in Nigeria, with the air at the faces saturated at a temperature of 87° to 90° F.

It may be objected that in these instances native labor is employed. That is so; but the native is subject to the same physiological laws as ourselves. It is perhaps worth remarking that physical exertion at ordinary external temperatures induces a rise in body-temperature which is seemingly as much a normal concomitant of the exercise at the augmentation of blood-circulation and respiration. There is apparently nothing uncommon in the body-temperature rising to 102° F. during exertion, and greater increases have been recorded. This increase in temperature is said to serve a useful purpose in facilitating the transfer of oxygen from the blood to the muscles, and in hot places it assists evaporation from the skin.

From an investigation of the efficiency of linen weavers, Weston (167) concluded that when the relative humidity was constant the productive efficiency of fine-linen weavers varied directly with the wet-bulb temperature up to a certain critical point. When the wet bulb reached 73° to 75° F. it was definitely unfavorable and produced undue fatigue and reduction of efficiency.

Orenstein and Ireland (168) determined experimentally that when the cooling power of the atmosphere was below 6 units by dry kata and 16 by wet kata the working efficiency of a native miner (stripped to the waist) was reduced. In bad places in the mine, where the cooling power was only 1.5 units dry kata and 5 wet, the average efficiency was only about 55 percent, the body temperature rose to an undesirable degree, and working under such

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conditions might cause extreme fatigue. These authors give the relation between efficiency and dry cooling power as follows:

Dry cooling power (millical. per sq. cm. per sec.)	1	2	3	4	5	6
Working efficiency, percent	50	60	70	80	90	100

Working in hot places was a greater strain in winter than in summer. Orenstein and Ireland (168) concluded that 4 hours' work was all an average native working continuously underground at full capacity could do efficiently under the worst conditions. The time probably would be somewhat longer where the dry kata was 7 units and the wet kata 19 units.

Experiments by Hill and Campbell (169) revealed that when the body is regarded as a machine the muscular efficiency is virtually the same under a cooling power of 3.9 dry kata as under one of 11.2. Their principal conclusion was that the higher cooling power had great advantage over the lower cooling power, mainly because the heart had less work to do and bodily comfort was maintained.

Wyatt (170) found that, beyond a temperature of about 70° to 75° F. and 80 to 85 percent relative humidity, the efficiency of weavers began to decrease.

The upper limit of temperature efficiently endured with muscular work was found by Yaglou (171) to be 80° effective temperature, and the comfort zone at rest was between 63° and 71° effective temperature. In a later report (172) he stated that between effective temperatures of 40° and 75° the amount of work performed is virtually constant; above 75° the output decreases gradually until 80° is exceeded, when the fall becomes very rapid. Men can perform almost twice as much work at an effective temperature of 70° as they can at 93°. Yaglou (172) concludes that from the point of view of efficient operation and of health and comfort of workers it is inadvisable to allow the effective temperature to exceed 80° in heavy industrial occupations.

Studies conducted by the New York State Commission on Ventilation (173) revealed that 23 percent less work was done in a stagnant atmosphere at 75° than in a fresh atmosphere at 68°. When fresh and stagnant conditions were grouped for the same temperatures from 68° to 75° the reduction in work was 15 percent. A comparison of fresh and stagnant conditions at the same temperatures revealed a reduction in work performed in stagnant air of 9 percent below that performed in fresh air.

One investigator (174) reported that, although temperature apparently had minor importance as a cause of fatigue, it had to be considered owing to its effect on production, as the output of a group of manual workers dropped 15 percent when the room temperature was raised from 66° to 75° F.

Within 2 months after the cooling plant at the Ooregum mine was started (159), development footage rose from 1,000 to 1,400 feet a month without any change in the number of ends working and without employment of additional

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workers. Also, the amount of granite walling built increased enormously. The results show that the installation of the plant was well worth while on the score of efficiency alone, without considering the greater depth to which air conditioning will permit mining to be carried and the satisfaction the improved working conditions caused among the miners.

Table 2, on the direct relationship between output and actual working conditions, was arranged by Yaglou (175) from results obtained by Bedford and Warner.

TABLE 2. - Working capacity of miners in relation to effective temperature and wet-cooling power

Effective temperature, °F.	Wet-kata cooling power	Rest pauses, minutes per hour	Tub-filling time, minutes	Relative output, percent
65.8	18.6	7.3	8.0	100
65.8	14.6	6.7	8.6	94
75.3	12.9	9.0	8.5	91
75.8	10.8	10.0	9.2	82
77.8	9.0	11.1	9.1	81
81.8	6.4	22.4	9.6	59

Compared with the reduction in work performance of about 41 percent found by Vernon and Bedford to occur between the wet-kata cooling powers of 5 and 19, Ehrismann and Hasse (176) report a performance period of about 40 percent (33 to 69 percent) between the wet-kata cooling powers of 6.3 and 8.2. Hasse (176) previously had found a difference of 100 percent (20 to 120 percent) in work performance between the cooling powers (5 and 19) mentioned by Vernon and Bedford. Ehrismann and Hasse (176) consider 28° C. (about 82° F.) effective temperature to be the limit for a full working period. However, they state that the reduction in working ability fluctuates continually, and it does not appear advisable to set a definite temperature limit - for instance, the 28° C selected as the full-time labor limit in the German hard-coal industry.

The Industrial Health Research Board of Great Britain (177) made the following recommendations regarding temperatures suitable for work in connection with the production of war materials:

1. In winter suitable temperatures are: For very light work, 65° F.; for active yet light work, 60° to 65° F.; for work involving more muscular exertion, 55° to 60° F.

2. In hot weather the temperature should be kept as low as possible.

Data from a study by the American Society of Heating and Ventilating Engineers (178) to obtain information for the guidance of labor, employers,

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and others interested in determining atmospheric conditions under which work can be done without harmful effects indicate that an increase in pulse rate of about 24 beats a minute accompanies a rise in body temperature of about 1° for moderate conditions of exposure. For more severe conditions, the pulse rate increases proportionately at a higher rate for the same rise in body temperature. Rises in body temperature of 1/2°, 1°, 1 1/2°, and 2° are accompanied, respectively, by increases in pulse rate of 12, 25, 38, and 70. The investigators (178) state that:

> The fact that rise in body temperature and increase in pulse rate always appear to be a positive index of exposure to hot conditions makes it seem most desirable to base any limitation, either on length of exposure or severity of a hot condition in which a man should work, on these two factors. As pointed out previously, rise in body temperature represents a more positive mathematical relationship to the atmospheric condition and, therefore, it should be accepted as the better index of the two.
>
> While this study was not designed particularly to determine the allowable rise in body temperature of workers in industry, the observations of the effect of temperature rise on subjects in this study as observed by the investigators and the medical men in attendance offer some basis for a limitation. These observations have led the authors to recommend that the limitations be so placed that no worker be expected to have more than 1 1/2° rise in body temperature.

Effect on Accidents

According to Bedford (179), the effects of excessively warm environments are not limited to the causation of discomfort and hindrance of production but influence also the health of the workers and their liability to accidents.

A study of all accidents that entailed absences from work of more than 3 days among 18,000 underground workers in British coal mines revealed that temperature had a distinct bearing on the liability to accidents. Those employed in seams where the temperature was 80° F. or more had 30 to 77 percent more accidents than those working at temperatures below 70° F. Accident severity, measured in terms of number of days lost per 1,000 hours worked, was greatest in the hottest mines, but the increase in accident severity was less than the increase in accident frequency. Temperature had no appreciable influence on the frequency of severe accidents causing prolonged disability. Minor accidents entailing disability of less than 10 days, however, were three times as numerous at the higher temperatures as at the lower ones. Table 3 (179) shows the effect of temperature on liability to accidents among workers at the coal face:

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TABLE 3. - Accident rates of coal miners in relation to air temperature

Temperature Range, °F.	Mean Temperature	Accident frequency per million hours worked		Accident severity (days lost per 1,000 hours worked)	
		1924-25	1927-28	1924-25	1927-28
Under 70...	63.9	104	133	3.5	4.4
70 to 79...	77.3	144	144	3.6	3.8
80 or over	82.8	184	173	4.5	4.8

The relation between age and accident frequency also was influenced by the temperatures at which the men worked, as is indicated by table 4 (179).

TABLE 4. - Accidents in seams per 1,000 men per year in relation to age and temperature

Age group	Temperature		
	Under 70°	70 to 79°	80° or higher
Under 30...	203	263	289
30 to 39...	186	219	251
40 to 49...	180	232	299
50 or older	191	331	344

Spalding and Parker (159) stated that another very important effect of the improved conditions resulting from air conditioning at the Ooregum mine was the reduction in number of trivial underground accidents. It had been noticed for some years that the accident rate fluctuated annually according to the temperature. As most trivial accidents result from fatigue or carelessness it is natural that they should occur more frequently under bad working conditions. Consequently, after the cooling plant was in operation there was a definite decrease in the number of accidents, as indicated in figure 1.

The following statement by Seymour (180) summarizes briefly some of the records of the relation between temperature and accident risks that have been made in various industries since the beginning of the first World War:

> It was found that munition workers showed least tendency to accidents when the temperature was between 65° F. and 69° F. The accident rate at temperature of 50° to 55° F. was approximately 35 percent higher for men and women. At temperature above 72° F. the rate also increased considerably by about 30 percent for men but only about 10 percent for women. This smaller increase in the women's accident rate may have been due to the fact that they adjusted their clothing to the conditions and wore lighter garments in hot rooms, or to their work, which was probably not so strenuous.

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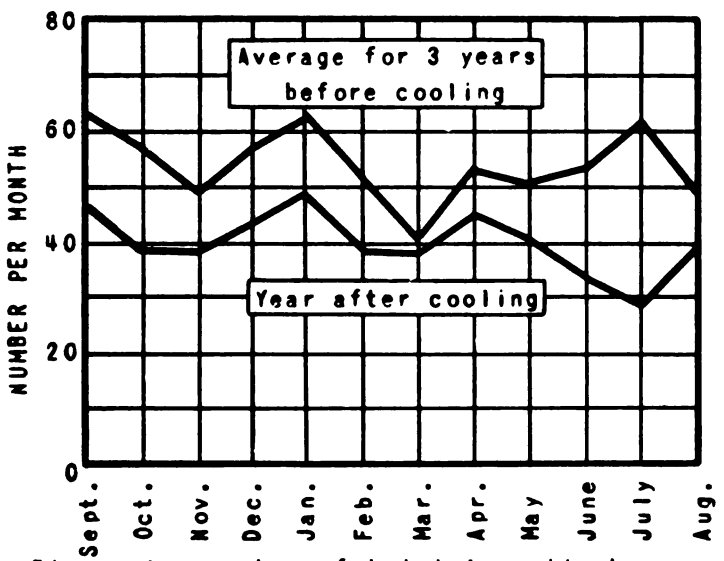

Figure 1.- Number of trivial accidents per month before and after cooling.

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In mines it has been found that those working on the hotter seams are more liable to accident than those working under more suitable conditions. An analysis of compensation claims made over a period of 4 years in 10 collieries showed a marked relationship between conditions of work and accident rates. Men at the coal face were found to have about twice as many accidents as men working elsewhere. Among coal-face workers those in places where the temperature was over 80° F. had, in one 2-year period, 70 percent more accidents than those who worked where the temperature was under 70° F., and the corresponding figures for those who worked at temperature of 70° to 80° F. was, in another period, 40 percent. The accidents in the hotter places generally tended to be more serious (in terms of days lost per 1,000 hours worked) than in the cooler places, though this was not always the case. Among workers underground other than those at the coal face, a similar increase in accident rate was noticeable where the temperature was high. It was noted that absences of more than 20 days due to accidents were practically the same at all temperatures, but that absences of 3 (the minimum period for claim) to 10 days were three times as numerous in hot places as in cool ones. It would appear that the greater number of shorter absences due to accident is not due so much to an actual greater number of accidents, but to the fact that where working conditions are bad the miner tends to stay away longer for a minor accident than he would if conditions were better.

Treatment of Heat Disease

Treatment of the various types of heat disease is a matter for the physician to determine in each individual case and will not be discussed in this paper. Attention might be called, however, to the statement by Guild (181) that on shipboard in tropical waters a victim of heat collapse usually is well on his way to complete recovery with no treatment other than 2 or 3 hours' rest on a cot in an air-cooled sick bay.

Prevention of Heat Disease

Heatstroke and other diseases resulting from exposure to abnormally high temperature and humidity can be prevented by the application of suitable physiological and physical measures.

Physiological Measures

Some persons are more sensitive to heat than others. This is especially true of those who are in a subnormal physical condition or who have suffered an attack of heat stroke or heat exhaustion. If possible such persons should avoid exposure to climatic extremes of heat or cold.

The ill effects of exposure to heat can be mitigated by careful attention to healthful living habits, such as avoidance of alcoholic excesses, eating proper food, and obtaining adequate rest.

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From data obtained by the Fatigue Laboratory of Harvard University, Talbott(163) summarizes the factors predisposing to increased susceptibility to heat as follows:

> The predisposing factors that increase the susceptibility to heat are for the most part known, and, once recognized, it is the duty of the industrial surgeon to take heed of them. Organic disease and ill health increase the susceptibility of the human body to sudden changes of temperature. This is especially evident in large cities during summer heat waves. Many of the victims have an organic malady that probably contributes to their breakdown with the excessive summer temperatures. In the various industries, quite the reverse is generally true of men who succumb to heat exhaustion. The men exposed to conditions favorable for the production of heat cramps have strenuous work to perform that would be impossible in the presence of an existing organic disease. And it need not be emphasized that no man should be allowed to work in high temperatures if any chronic disease is present of sufficient severity to produce symptoms.
>
> Alcoholism has been accused of increasing the susceptibility to heat exhaustion since the earlier discussion of this condition. In the evaluation of the importance of alcoholism as a predisposing factor, it is necessary that any statement made be interpreted intelligently and without moral prejudice. It is a sound statement that an intoxicated man should be prohibited from driving an automobile on a public highway. It is not a sound statement that all men exposed to excessive heat should be total abstainers. In the first place you could not enforce such a rule. Secondly, there is little evidence that indicates such a rule should be enforced. It is very important for us all to know at what level alcoholism begins to be important. Chronic alcoholism may produce organic disease of the heart, stomach, liver, or the brain. When these are observed in any workman, he should be handled as any other case of chronic disease and removed to an easier job. Only a very small percentage of the workmen in a large mill are in such a category.
>
> The belief that alcoholism is a predisposing factor to heat cramps is probably a result of the effect produced by acute alcoholic bouts and not by chronic alcoholism. Many acute bouts are accompanied by nausea and vomiting, and little or no food is retained as a consequence. With the inadequate ingestion of food, there is generally an inadequate ingestion of the mineral salts normally consumed. If, in addition, vomiting and diarrhea are present, the reserve of salt and water in the body may be reduced to a critical level. This sequence of events is intimately related to the pathogenesis of heat cramps that will be considered later.

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I think we can say dogmatically, that anyone who has been on an alcoholic bout and has ingested little food in the previous 24 hours is a fit candidate for heat cramps and should not be allowed to work until he has fully recovered.

In the above discussion, reference to alcohol implied the stronger drinks rather than beer. Certain advantages may be gained from the consumption of beer in moderate quantities. In the industrial section of the Ruhr in Germany where the incidence of heat cramps is presumably low, salted beer is the common beverage; likewise, colliers in the English mines use salted beer for the prevention of cramps.

A third predisposing factor is a previous period of inadequate assimilation of food. Alcohol may be the contributing cause of such a diminished intake as has been previously mentioned. Gastrointestinal upsets with vomiting or diarrhea in the period before the onset of cramps are frequently admitted by the patients. Less severe disturbances may be associated with little more than loss of appetite. It is significant that several of the men in our study had either omitted breakfast or lunch on the day of admission to the hospital. There is little evidence that constipation in itself is important enough for us to pay special attention to it. Constipation may be a symptom of an existing chronic disease and when this is the fact the workman should be treated as any other with chronic disease.

A recent attack of cramps or prostration not adequately treated renders the subject susceptible to a second attack, which is usually more severe. It is a common practice for many men who have very mild cramps not to report them to the medical officer but to go directly home and apply domestic remedies. This is usually successful, but not always. I believe it a wise policy to allow all men who have had heat cramps or heat prostration, although very mild, a day off without penalty. There should be no stigmata attached to the reporting of any condition brought on by high temperature, however mild the symptoms. This advice applies to men who have mild symptoms only. All others with moderate or severe symptoms should be prohibited from working and not allowed back on the job until fully recovered, and passed upon by the company surgeon.

Another factor less well defined but hardly open to question is bad hygiene, which may include living conditions, badly chosen food, irregular habits, and inadequate rest. The necessity for periodic physical examinations and an effective social service system to remove many of these predisposing factors should be obvious.

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The use of salt in drinking water to replace the chloride lost from the body through sweating has been recommended as a preventive of fatigue and heat cramps in workers in hot places. According to Moss (182), the amount of salt that should be added to the drinking water will depend on the severity of the work to be done, but 5 to 10 grams to a gallon of water usually is sufficient.

Oswald (183) eliminated cramps among workers in gas-retort houses by introducing a saline drink composed of a stock solution of 120 grams potassium 180 grams sodium chloride, and 1 liter of water; this was added to 213.3 liter (47 gallons) of water to form the drink.

Many companies now provide salt tablets for their employees to add to the drinking water to prevent the ill effects of exposure to excessively hot working conditions.

Elmer and Kaufmann (184) made comparative tests on the heat regulation and sweat secretion of persons on diets with high, normal, and low sodium chloride content. They found that persons on a sodium chloride-deficient raw diet generally tolerated the sweating better than others. The perspiration began later, the skin and body temperature did not rise as high, the quantity of perspiration was less, and its percental as well as absolute sodium chloride content was lower. According to the authors quoted, the decreased elimination of sodium chloride in the perspiration and in the urine indicated an adaptation of the organism to the decreased sodium chloride intake. Other possible causes suggested for the improved heat regulation while on a raw diet were increased elimination of heat by conduction and particularly by radiation due probably to decreased water and sodium chloride content or to better blood perfusion of the skin (vasomotor heat regulation); protein deficiency; abundant mineral content (especially potassium); and the influence of the diet on the sympathetic nervous system.

The following statement from Industrial Medicine (185) more or less summarizes the principal factors regarding the use of salt as a preventive of heat cramps:

> From the cases mentioned here, and from a mass of other evidence, it is clear that heat cramps are caused by a lowering of the body's salt supply, through profuse sweating... and that this condition can be corrected very simply by providing workers who sweat with additional salt to make up the loss.
>
> This can best be done by regulating the amount of salt to the amount of water the workers drink. Those who sweat a great deal will drink more water, and get more additional salt than workers who do not sweat as much, and consequently drink less water.
>
> In general, there are two ways this salt can be supplied. One is to add it directly to the drinking water. Many of the earlier articles on the subject mention this method. Later evidence seems to favor the use of salt tablets. One 10-grain

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tablet, taken with a drink of water at frequent intervals during the day, is found to be an effective means of maintaining the normal salt balance. This method gets the desired salt into the system without affecting the taste of the water or creating excessive thirst.

Most industrial physicians and surgeons have concluded that the correct amount of salt for the average worker to take during the day is 1 teaspoon of salt (or its equivalent in salt tablets) for each gallon of water he drinks. Eight 10-grain salt tablets are almost the exact equivalent of 1 teaspoon of salt.

Workers doing average hot work will drink about 1 gallon of water per day.

Workers doing the hottest, hardest work seldom drink over 2 gallons of water per day.

Workers doing light to medium work, 5 to 6 tablets per day.

Workers doing medium to heavy work, 8 to 10 tablets per day.

Workers doing extra-heavy, hot work, 12 to 15 tablets per day.

Another physiological method is that being used in South Africa to "acclimatize" native workers before they are allowed to perform hard work in the hot places in the mines. Deaths from heatstroke became such a menace in the City Deep mine (155) that it was necessary to evolve a practical, economical, and effective system of underground acclimatization. The first recorded investigation into deaths from heat on the Witwatersrand was made in connection with four cases of sudden death "presumably from heatstroke" that occurred in the Village Deep mine at the end of 1925 and beginning of 1926. As a result of this inquiry it was recommended that -

> As far as possible, natives fresh to mining conditions should not be sent to work in hot parts of the mine until they have had an opportunity of becoming acclimatized and of learning work in cooler parts.

The first instructions relative to acclimatization were issued to underground officials of the City Deep mine in 1926 after the first fatal case recognized as heatstroke had occurred in the mine. The instructions were that newly employed natives without previous experience were to be engaged in light work in specially selected places for 10 days and natives with previous underground experience for 5 days. However, deaths from heatstroke continued to occur - three in 1927, four in 1928, and in 1930 "the number of deaths increased alarmingly." Five of the seven deaths were natives who had completed the 14-day period of acclimatization work and two were natives who had been recruited locally and had completed a 7-day period of acclimatization.

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As heatstroke deaths continued to be a serious menace in spite of the extra acclimatization precautions, and the loss of working efficiency was two-thirds of a normal shift during the acclimatization period, greatly affecting the financial position of the mine, the question of susceptibility to heat was considered. Relatively few of the natives working in bad underground conditions showed any marked effects of such exposure, therefore it was reasonable to assume that those who developed heatstroke were "abnormally susceptible." This possibility led to "heat-tolerance tests" by which it was hoped to prevent the susceptible natives from going to their death underground For this purpose new, unacclimatized natives were given the test on employment for underground work after 14 days of underground work and after 1 month of underground work. The rise in body temperature was the most consistent, reliable, and accurate index of the degree of acclimatization and, therefore, of heatstroke susceptibility. As correlation between pulse rate and body temperature could not be established, it was concluded that pulse rate is not an indicator of the efficiency of the control of body temperature.

Definite acclimatization was considered established when the temperature of the subject remained consistently below 100.6° throughout the test and failed to rise above this in subsequent tests. The test revealed (186) that about 60 percent of the natives were normal; that is, the blood temperature rose rather irregularly for the first 3 days and then remained consistently at 100° to 101.4° F.; about 25 percent were heat-tolerant, that is, their temperatures did not rise above 100° F.; and 15 percent were heat-intolerant - their temperatures rose rapidly immediately at the beginning of the test and subsequent tests did not improve their heat-control mechanism. These tests led to controlled acclimatization routine for new native workers.

Dreosti (155) concluded that it was possible for acclimatized "normal" natives to work in saturated air at 95° F., which is equivalent to a wet kata of about 1.0. Earlier investigators had expressed the opinion that with a wet kata reading of 5.0 the blood temperature began to rise and efficiency dropped considerably. Lange (187), however, was of the opinion that all except heat-intolerant natives could work without danger of heatstroke or loss of efficiency in temperatures of 90° to 89° and 90° to 89.5° F if wet-kata readings were not above 5.0.

Utilizing the knowledge gained, it has been possible to groups new native workers according to their individual degree of heat tolerance and allot periods of acclimatization of economic significance. According to Dreosti (155) the results have been surprisingly successful in preventing heatstroke and increasing the working efficiency of the mine.

Physical Measures

Some of the physical measures for the control of atmospheric conditions in mines detrimental to the health and efficiency of the workers will be discussed in detail in part III of this series, and therefore they are not included in this paper.

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Summary

1. The physiological aspects of the principal physical qualities of mine air - temperature, humidity, motion, and barometric pressure - are discussed, with emphasis on high temperatures.

2. Although the data are intended mainly for the mining and allied industries, they are applicable to many defense industries as well as to conditions in activities of the Army, Navy, and Air forces.

3. An average mean air temperature of 60° to 70° F. for day and night together is said to be the optimum for health and physical vigor. The range of optimum temperature among diverse races is small in contrast to the great range of the mean temperature of the regions where they live. Adaptation to an environment averaging between 60° and 80° F. apparently is a primitive trait.

4. Abnormally high and low temperatures have great influence on physical activity, accidents, sickness, and mortality. Climate and weather exert a profound influence on such factors as diet, occupation, and recreation, which in turn affect human morbidity and mortality.

5. Less is known about the physiological effects of low temperatures than of high temperatures. However, effects of very cold climates on health and disease are similar to those of very hot climates.

6. Information on the effects of change in barometric pressure is limited, although there are definite indications that storm changes in pressure profoundly disturb physiologic functions of mind and body.

7. Excessively high temperature and humidity are found in mines in Arizona, California, Colorado, Michigan, Montana, and Nevada as well as in some others in the United States and in mines in India, South America, and South Africa.

8. The effects of exposure to high atmospheric temperature and humidity are said to be acute (sunstroke) and chronic (heat stroke or heat exhaustion).

9. Some authorities classify the symptoms caused by heat into three groups, as heat cramps, heat exhaustion, and heat retention.

10. Heat cramps are muscle cramps that may occur very abruptly on exposure to very high temperature. The muscles of the shoulder, calf, and the flexor group of the forearm are most commonly affected. The muscles of the abdominal wall and the fingers are affected to a less degree.

Heat-exhaustion patients exhibit symptoms of faintness and prostration and suffer from shock, with weak, rapid, thready pulse, low blood pressure, normal or subnormal temperature, and irregular respiration.

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Heat-retention cases are characterized by a rise in body temperature, accompanied by nervous restlessness, headache, vertigo, and great excitement. The pulse rate usually is irregular and rapid (120 to 140), body temperature rises from 3° to 10° F., and respiration at first is rapid and labored, later becoming irregular and stertorous. The patient may topple over in a stupor and die with startling suddenness.

11. Bureau of Mines investigators observed dizziness, physical weakness or exhaustion to a marked degree, inability to think quickly or accurately, and nausea and headache during exposure to the still, hot, humid atmosphere of metal mines.

12. According to South African investigators, rise in body temperature is the most consistent, reliable, and accurate index of the degree of acclimatization, therefore individual acclimatization and susceptibility to heat stroke can be measured.

13. Investigations by the Bureau of Mines indicate that pulse rate probably is the best index of discomfort resulting from exposure to high air temperatures.

14. Air conditions that have the greatest effect on the circulatory system are humidity, temperature, air movement, and barometric pressure.

A marked increase in relative humidity depresses the circulatory system and decreases the blood pressure; a marked decrease in temperature stimulates the circulatory system and decreases the blood pressure; a marked increase in barometric pressure increases the blood pressure, while a marked fall in barometric pressure increases the pulse rate.

15. Although no arbitrary rate at which certain symptoms occur has been determined, consensus of opinion is that very uncomfortable sensations are felt after the pulse rate exceed 135 a minute, and the atmospheric condition becomes unbearable when the rate exceeds 160 a minute.

16. Men accustomed to working on hot jobs are said to show no ill effects with their hearts beating twice the normal rate, provided they have normal rest periods during their hours away from work.

17. Pulse rate and blood pressure are indexes of the strain under which the heart is working and not of the ability to control rise in body temperature; acclimatization is accompanied by "acclimatization of the heart By forcing cessation of work, symptoms of a fatigued heart (dizziness, weakness, or collapse) protect an overtaxed heart from further exertion.

18. The blood of patients suffering from heat cramps or heat exhaustio shows a decrease in sodium and chloride, but little change occurs in heat-prostration cases, which some investigators consider most important for the chemical differentiation of heat cramps from heat prostration.

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19. Administration of saline solutions relieved the symptoms of patients (especially those having cramps) whose blood showed disturbance of salt balance, while other patients were unaffected by the treatment.

20. Some investigators have found depletion of blood sugar and dehydration in heat-exhaustion cases out of proportion to the diminished chloride content of blood plasma and recommend the administration of glucose in severe cases. After the introduction of gum drops (containing approximately equal parts of glucose and granulated sugar) into the works of a steel company heat-exhaustion cases decreased from 326 in 1928 to 67 in 1935.

21. Aside from voluntary modification of his surface by posture and of his insulation, heat loss in man depends on the temperature of his skin and the rate at which water is evaporated therefrom.

22. Exposure to abnormal air conditions affects the excretion of water and carbon dioxide from the skin as well as secretions from the sweat and sebaceous glands.

23. It is estimated that the skin and lungs of a healthy person give off together about 550 grains of moisture an hour - enough to raise the relative humidity of the vapor in 380 cubic feet at 60° F. from 75 percent to complete saturation.

24. Loss of water from the skin may occur in two ways - by evaporation of water that has permeated through the general surface of the skin (osmosis or diffusion) and by evaporation or trickling down of sweat secreted by the sweat glands.

25. Virtually all the loss of water through the skin is said to be osmotic until the air temperature reaches 85° F. Tests revealed an osmotic loss of 117 grams an hour with an air temperature of 101° F.

26. The average quantity secreted in 24 hours by the sweat glands is said to range between 700 and 900 grams. One investigator estimated that the amount of moisture secreted by the skin in calculated perspiration was at least 1,500 grams daily.

27. Tests made on sheet-mill crews revealed a fluid loss through the skin of 20 or more pounds (2 1/2 gallons) of sweat during an 8-hour work period.

28. About 7 or 8 grams of carbon dioxide are excreted through the skin in 24 hours during complete rest at 20° to 33° C.; when the temperature however, reached the point at which sweat appeared (about 33° C.), the amount of carbon dioxide excretion suddenly increased three or four times.

29. The elimination of acids, chiefly carbon dioxide, through the lungs, urine, and sweat during exposure to heat is said to leave an excess of alkali in the blood, which is eliminated through the sweat and urine; this may explain some of the painful consequences of the uncritical application of heat to the body.

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30. Soaking of the skin due to working in hot places lowers the vitality and facilitates the entry of bacteria. Boils are prevalent in some mines where the temperature is around or over 93° dry bulb and 75° or more wet bulb.

Skin affections among miners have been attributed to the change in the normal reaction of the skin to an alkaline reaction due to greatly increased sweating.

31. Man is said to lose 75 to 85 percent of his heat by way of the skin and only 14 percent by way of the lungs. The ventilation of the lungs is markedly increased when the air temperature is high and the respirations increase in depth and number.

32. Studies in an artificial mine revealed that in repose the ratio between the water lost by respiration and that lost through the skin was about 40 percent but during work fell to 12 to 16 percent.

33. According to some investigators, as little as 1° of fever affects the mental processes, and before the heart has lost its efficiency or the respiration is more than quantitatively affected the coherence of the mind is gone.

34. The normal heat of the blood is thought to be the most satisfactory for muscular work. The toxic products of fatigue are augmented in the muscles with increased temperature.

35. Resistance to infection is affected by the ease of body-heat loss and the combustion level allowed the individual. Mice adapted for 3 weeks to 90° F. and 60 percent relative humidity succumbed with only one-fourth the injected dose of organisms that was required to kill mice adapted to 65° F. An intermediate-size dose killed all the mice from the hot room, while all from the cold room survived.

36. In tests on the working power of muscles the amount of work performed, expressed in percentage, by muscles exposed to high, intermediate, and low temperatures was 76, 85, and 100, respectively.

37. The following air-temperature limits for work in mines have been set by some investigators: 78° F. wet bulb in still air and 85° F. in air moving 135 feet a minute; at 80° the amount of work performed decreases; at 85° hard work is virtually impossible; and at 88° F. it is impracticable for unacclimated persons to remain in the air for long periods.

38. The efficiency of the underground worker is said to be in direct proportion to the separation of wet- and dry-bulb temperatures of the main ventilating currents in stopes and other working places. The critical wet-bulb temperature at which man is likely to collapse is said to be 93°. In a mine in which the temperature is increasing slowly as it is being deepened the critical stage is reached suddenly, and an increase above that stage of 1° in wet-bulb temperature means the difference between being just able to carry on and complete failure to do so.

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39. Studies by the Bureau of Mines revealed that work in mines in still, almost saturated air was easy at 75° F., but at 80° F. the physical effort and physiological effect were perceptibly greater, while at 90° it was impossible to endure the usual rate of work (ladder climbing) for a full hour.

40. Tests on a group of 23,000 miners who had worked 2 to 6 years in collieries of Great Britain revealed that men working at a dry-bulb temperature of 70° F. lost 3 percent of the time from sickness; at temperatures between 70° and 79° F. the time lost was 4.5 percent; and at temperatures exceeding 80° F. the time lost rose to 5 percent. When the data were based upon wet-bulb temperatures the time lost at temperatures below 66° F. was 3 percent, between 66° and 69° it was 4.2 percent, and above 70° F. it was 5 percent.

41. It has been suggested that in addition to difficulty in keeping down the body temperature, a possible cause of reduction of efficiency during work in high wet-bulb temperature is the impairment by the hot, damp air of the passage of oxygen from the air in the lungs to the blood.

42. Between effective temperatures of 40° and 75° the amount of work performed is virtually constant; above 75° the output falls gradually until 80° is exceeded, when the fall becomes very rapid. Men can perform almost twice as much work at an effective temperature of 70° as at 93°. It is inadvisable, therefore, to allow the effective temperature to exceed 80° in heavy industrial occupations.

43. The Industrial Health Research Board of Great Britain has recommended the following as suitable temperatures for work connected with the production of war materials: In winter, for very light work, 65° F; for active yet light work, 60° to 65° F.; for work involving more muscular exertion, 55° to 60° F. In hot weather the temperature should be kept as low as possible.

44. According to studies by the American Society of Heating and Ventilating Engineers rises in body temperature of 1/2°, 1°, 1 1/2°, and 2° are accompanied, respectively, by increases in pulse rate of 12, 25, 38, and 70. Therefore, any limitation on length or severity of exposure to hot conditions should be based on body temperature and increase in pulse rate. It has been recommended that no worker be expected to have more than 1 1/2° rise in body temperature.

45. Excessively warm environments not only affect the health and efficiency of workers but increase their liability to accidents. Those of 18,000 underground workers in British coal mines who were exposed to a temperature of 80° or more had 30 to 70 percent more accidents than those working below 70° F. The increase in accident severity was less than the increase in accident frequency. Minor accidents entailing disability of less than 10 days were three times as numerous at the higher as at the lower temperature.

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46. Treatment of the various types of heat disease is a matter for the physician to determine. However, 2 or 3 hours' rest in an air-cooled room is said to start a victim of heat collapse well on the way to recovery.

47. Heat stroke and other diseases resulting from exposure to abnormally high temperatures can be prevented by avoidance of exposure of those who are particularly sensitive to heat, who are in a subnormal physical condition, or who have suffered an attack of heat stroke or heat exhaustion.

48. The ill effects of exposure to heat can be mitigated by careful attention to healthful living habits, such as avoidance of alcoholic excesses, eating proper food, and obtaining adequate rest.

49. The use of salt - 5 to 10 grams to 1 gallon of water - in drinking water to replace the chloride lost from the body through sweating is recommended as a preventive of fatigue and heat cramps in workers in hot places.

50. A method (developed in South Africa) of "acclimatizing" native workers before they are allowed to perform hard work in the hot places in the mines has been successful in preventing heatstroke and in increasing the efficiency of the workers.

51. Some of the physical measures for the control of atmospheric conditions in mines detrimental to the health and efficiency of the workers will be discussed in detail in part III of this series of circulars.

Conclusions

As applied to mines and those who work in and around them, some conclusions are offered based largely upon data contained in this circular but including also some observations from investigations as well as experience of the authors.

1. In hot, humid, stagnant air men are likely to be affected by dizziness or inability to think clearly or quickly, or they may faint at an inopportune time and be killed; also, there have been numerous instances of men dropping dead from heart failure in hot places in mines.

2. Rock temperature generally increases with depth, the rate of increase ranging from 1° F. or more per 100 feet of depth in certain districts of the western part of the United States to but 1/2° or 1/3° F. per 100 feet of depth in other regions, both in the United States and in foreign countries. In Montana, rock temperature in copper sulfide veins is about 108° F. 3,800 feet below the surface, the rate of increase being about 1° per 100 feet of depth. In a lead sulfide vein in the Coeur d'Alenes in Idaho rock temperatur 2,000 feet below the surface was but 50° F. In a Michigan copper mine with native copper ore rock temperature was about 82° F. 5,000 feet below the surf

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In a gold-bearing quartz vein in Arizona the rock temperature was 90° F. 600 feet below the surface, while in a quartz deposit bearing copper sulfide in another Arizona district rock temperature 600 feet below the surface was but 70°. Temperature of coal in place in coal mines in the United States is rarely above 70° F. and is generally much lower. Magazine articles give the rock temperature of the Kolar gold field in India at 118° F. 6,100 feet below surface and 98° F. at the 4,000-foot level of the St. John Del Rey mine in Brazil, while it is calculated that at the 8,000-foot level of the City Deep mine in South Africa the rock temperature will be but about 97° F. (188).

3. With dry-bulb temperatures below 75° F., mine working places may be comparatively comfortable, irrespective of air movement or relative humidity, if the air is not deficient in oxygen or impregnated with toxic or noxious gases.

4. With temperatures between 75° and 95° F., especially if the relative humidity is high, still air is likely to cause excessive perspiration in the performance of even light manual work, possibly headache and nausea, frequently mental dullness, and usually a rise in body temperature.

5. With temperatures of 80° to 95°, stagnant air is oppressive even if pure and the relative humidity low.

6. With temperatures of 90° to 95° F., stagnant air, at low humidity, is bearable if it is given a velocity of 500 linear feet a minute.

7. When air temperatures rise above blood heat (98° F.) virtually the only means to prevent discomfort or lowered efficiency is rapid circulation of the air. In heat experiments conducted by the Bureau of Mines and the United States Public Health Service (189), a man whose body temperature had risen to 100.2° F., after remaining 45 minutes at rest in still air at 97 1/2° F. and 90 percent relative humidity, walked 200 feet along a level and carried a short ladder back to his resting place; this slight effort in the hot humid, stagnant atmosphere forced his body temperature to 102.6° F., indicating the probable effect on body temperature of trying to do hard work in temperatures higher than 100° F.

8. Until dry-bulb temperature approaches 75° F., a relative humidity virtually up to saturation causes little or no discomfort, even though the air is still, unless the air is depleted of oxygen or is charged with comparatively large quantities of CO, CO_2, or other noxious gases. When such air is given a velocity of 25 linear feet or more, work can be done normally.

9. With the relative humidity 85 percent or more and the temperature 75° to 85° F., stagnant air, even when pure, is oppressive, and its oppressiveness is greatly intensified with even a small decrease in oxygen supply or increase of CO_2. However, when comparatively pure air of this sort is given a velocity of 100 linear feet a minute a miner feels no appreciable discomfort when working fairly hard.

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10. Stagnant air, regardless of purity and humidity, is oppressive at 90° to 95° F., and the oppressiveness increases as the air approaches saturation. With a velocity of 400 linear feet or more a minute, such air is not particularly oppressive, and with a velocity of 1,000 or more linear feet a minute the effect is pleasant, particularly if the relative humidity is not more than 95 percent.

11. When temperatures reach 100° F. or higher, and the relative humidity is close to 100 percent, even a comparatively high velocity gives little relief. On the other hand, air with a temperature as high as 110° F. but with a relative humidity of 85 percent or less, although distinctly oppressive when still, is readily endurable when it has a velocity of 1,000 linear feet or more a minute. Hence, if adequate movement is supplied, the relative humidity is not a deciding factor until the temperature exceeds 100° F. and humidity approaches 100 percent.

12. Although the effects of underground air are greatly influenced by temperature, humidity, and gases, velocity of air probably has greater importance than all other agencies combined, with the possible exception of the removal of poisonous gases. In general, workers can be comfortable, healthy, and efficient if the air in which they work is circulating, even though that air is comparatively hot, humid, and to a considerable extent vitiated. The effect of even slight air movement was noticed by the senior author in a western mine where the workers in a stope with stagnant air at 79° F. and a relative humidity of 86 percent were accustomed several times daily to climb to the level above to "cool off" in air which, although actually 3° hotter and with 5 percent greater relative humidity than the air in the stope, moved at a rate of 150 linear feet a minute.

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